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Loading of rural distribution tranformers

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LOADING OF RURAL DISTRIBUTION TRANSFORMERS

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INTRODUCTION

Presently used methods of estimating loads on distribution transformers are not entirely satisfactory for use in selecting sizes of transformers serving single consumers. Most of these transformers are found in rural areas. The Rural Electrification Administration (21) reports approximately 1.25 consumers per transformer for the 4.6 million consumers on the lines of their borrowers. Since REA-financed cooperatives serve about half of the farms in the United States (12), it follows that more than 7 million distribution transformers are in use in all rural areas.

The load growth on the average farm in the United States is predicted to double in anywhere from 5 to 12 years (11, 12, 18, 21). If the rate of load growth is this great, nearly a million distribution transformers in rural areas will require changing to larger sizes each year. Making transformer changeouts is a routine matter, but deciding when to change is quite difficult.

Studies of the loading of distribution transformers have been concerned primarily with transformers in urban areas serving a number of consumers. The diversity among the peak demands of the individual consumers gives a high transformer load factor. As a result the required transformer capacity may be determined satisfactorily from energy consumption records or by other means. Where a transformer serves a single consumer, the transformer load factor is likely to be low, making energy consumption unreliable as the sole predictor of required capacity.

If a better method were available to enable power suppliers to estimate more accurately the loading on transformers serving single consumers, both consumers and power suppliers would benefit. Fully loaded distribution transformers are advantageous to power suppliers. As about 20 percent of the investment in rural distribution systems is in transformers (21), the installation of excess transformer capacity materially adds to plant investment. Line loss usually is increased upon enlarging the capacity of transformers, since the increase in excitation loss is greater than the decrease in resistance loss. In a study of the optimum capacities of components of distribution systems, Lawrence, Reps, and Patton (16) found that the greater the load on transformers, the lower the cost of supplying service.

Some disadvantages are present for the power supplier with overloaded transformers. The transformer failure rate is increased and replacements on an emergency or overtime basis are more costly than if transformer changes were planned in advance of serious overloading. Voltage regulation is not as good as for underloaded transformers, and small losses in revenue result from the reduction in energy consumption of voltage-sensitive loads. Also, consumer relations are likely to be poor if voltage regulation and service continuity are not satisfactory. As a result load growth may be less rapid.

The development of an improved method of estimating the maximum demands on transformers serving farms and other rural loads would allow more accurate transformer loading, and thereby would reduce the cost of supplying electric energy and improve voltage regulation and service continuity. Agencies cooperating in the development of a method that may have advantages over those presently used are: the Farm Electrification Research Branch, Agricultural Engineering Research Division, Agricultural Research Service, U. S. Department of Agriculture; the Iowa Agricultural and Home Economics Experiment Station; and the Rural Electrification Administration.

REVIEW OF LITERATURE

Many methods of loading distribution transformers are being used by various power suppliers, but none is completely satisfactory for transformers serving single consumers. Before reviewing the literature describing some of these methods, loading limitations of transformers will first be summarized.

Limitations on Transformer Loading

Lawrence and Lockie (15) suggest categorizing into three areas the limitations restricting the loads that may be placed on distribution transformers. Firstly, there is a thermal limit. If the load is too great, the temperature of the transformer increases and life expectancy is reduced. Secondly, there is an economic limit. If investments in transformers are reduced by overloading, some operating costs such as losses caused by the resistance of the windings increase exponentially with load. For loading beyond certain limits it may be advantageous economically to increase the transformer size. Thirdly, there is a voltage limitation. If the regulation of a transformer exceeds that allowed in the system design, voltage below the acceptable limit at the service entrance results.

Thermal limitation

The American Standards Association's publication, Guide for Loading Oil-Immersed Distribution and Power Transformers, (7) is the accepted standard for the thermal limitations on loading distribution transformers. The allowable winding-temperature rise of the transformer is 55° C. in an ambient temperature of 30° C. If the daily average temperature during any 24-hour period exceeds 30° C., the ASA Guide recommends reducing the load 1.5 percent below rated kva. for each degree centigrade that the average temperature of the cooling airs exceeds 30° C. Transformers may be loaded continuously an additional one percent of the rated kva. for each degree centigrade that the daily average temperature is below 30° C. Continuous loads greater than 133 percent of rated kva. are not recommended.

Transformers may be overloaded substantially for short periods without exceeding the 55° C. temperature rise although some of the transformer life expectancy is sacrificed. The following table from the ASA Guide (7) shows the short-time overload capabilities of transformers with a moderate sacrifice of life expectancy.

Table 1. Capability table for self-cooled transformers at a 30° C. ambient temperature with moderate loss of life expectancy

Duration of peak load (hours)	Ratio of allowable load to nameplate rating			
	Recurrent, following 50% load	Recurrent, following 70% load	Recurrent, following 90% load	Recurrent, following 100% load
0.5	2.00	2.00	2.00	2.00
1.0	2.00	1.95	1.86	1.81
2.0	1.72	1.67	1.50	1.48
4.0	1.38	1.36	1.33	1.32

Data collected by Altman and Jebe (4) show that rural loads normally have low load factors, and therefore, the loading permitted under "Recurrent, following 50% load" probably best describes the usual transformer loadings in rural areas.

Several authorities are of the opinion that modern transformers perform consistently better than indicated by the ASA Guide. According to Beavers (9), the ASA Guide recommendations were based on manila paper as the insulating material between turns of transformer windings rather than the kraft paper now used. He states also that the semi-sealed transformers referred to in the guide are now obsolete, whereas modern transformers are dried more completely and sealed in the factory. Tipton (26) reports small concentrations of certain amine compounds in the transformer oil significantly improve aging characteristics of cellulose insulation. Therefore their use permits overloads 10 percent higher than recommended by the ASA Guide.

An electrical trade magazine (19) reports the use of a rating system by four transformer manufacturers which allows the power supplier to take advantage of the increased capability of modern transformers. In addition to the ASA rating for a 55° C. temperature rise, a second rating 12 percent higher is given which is based on a 65° C. rise.

These thermal limitations important for urban transformers have relatively minor importance for farm transformers. Baker (8) reports a failure rate from overloads of less than 0.5 percent on the lines of the Georgia Power Company. In a private communication Harry R. Smith of the Rural Electrification Administration reports that an analysis of equipment failures of REA-financed borrowers shows a very low number of farm transformers failing from overload.

Economic limitations

Lockie and Book (17) list the economic factors determining optimum loading as: effect of loading on service-life expectancy; cost of exciting vars; cost of load and no-load losses; carrying charges on investment; changeout cost; load characteristics; and regulation in the transformer. They state that extensive testing and field experience offer convincing proof of the negligible effect on life expectancy of economical loading of modern transformers and of the negligible cost of carrying charges on capacitors to supply exciting vars in comparison to other economic factors.

According to Book (10) the no-load or iron loss of a transformer is a constant value independent of the load while the load or copper loss varies with the square of the load. The copper loss for a typical transformer at rated load is approximately two and one-half times the iron loss. Loads above rating would result in greatly increased copper loss. For example, at 200-percent load on the typical transformer, the copper loss is 10 times the iron loss.

Book (10) worked out the annual operating cost for various sized distribution transformers by using published data on the transformer characteristics and assuming values for such economic factors as the cost of changing the size of a transformer, energy cost, and rate of capitalization. For a typical 5-kva. transformer operating at a 30-percent load factor, he found that an annual average load of 3.3 kva. could be served before economic considerations dictated a change to a larger transformer. Under these conditions, the maximum one-hour demand was 11 kva. At 70-percent load factor, the economical change point was at a demand of 8.6 kva.

Since the load factors of most farms are below 30 percent (4), even greater maximum demands may be served before economic limitations make it advantageous to increase the transformer sizes. Economic limitations, however, are not usually the controlling ones in loading transformers for consumers in rural areas as other limitations are reached earlier.

Voltage limitations

The controlling limitation on the loading of transformers serving single consumers most often is voltage regulation as this limitation is usually reached before those imposed by thermal or economic considerations. Gibbs (14) defines transformer voltage regulation as the change in secondary voltage, expressed in percentage of rated secondary voltage, which occurs when the rated kva. output at a specified power factor is reduced to zero, with constant impressed primary voltage. The formula is

$$\text{Percentage regulation} = mR + nX + \frac{(mX-nR)^2}{200},$$

where m is the power factor of the load expressed as a decimal, n the reactive factor of the load expressed as a decimal, R the percentage effective resistance drop at 75° C., X the percentage reactance which is equal to $\sqrt{Z^2-R^2}$, and Z the percentage impedance at 75° C. The squared term in the formula is so small in comparison with the other terms that, practically speaking, it may be neglected. The percentage regulation then becomes a linear function of the load current.

The percent regulations of 5-, 10-, and 15-kva. transformers of one manufacturer (28) at a rated 80-percent power-factor load are 2.6, 2.3, and 2.1 percent, respectively. Assuming a linear relationship of regulation to load, and a 200-percent load, voltage drops of 4.2 to 5.2 percent may be expected in these transformers. The Rural Electrification Administration (20) recommends that the voltage drop in distribution transformers be held to 3.5 volts on a 120-volt base or 2.92 percent. The loading for 80-percent power-factor loads is thus restricted to from 112 to 135 percent of the transformer rating depending upon the size. The thermal limits imposed by the ASA Guide (7) permit 200-percent loading for one-hour duration loads following a 50-percent load. Voltage-regulation limitations therefore may be expected before those imposed by thermal considerations.

Methods of Estimating Transformer Loading

The transformer loading problem is mainly one of identifying consumers with transformers overloaded beyond desirable limits. Many methods of identifying these transformers have been suggested. The most common ones are as follows: transformer burnouts and voltage complaints; demand meters; copper-temperature indicators; demand estimations based on appliances served or energy consumption; and demand estimations based on a combination of appliances served and energy consumption.

Transformer burnouts and voltage complaints

Book (10) reports that in the past transformer changeouts were governed either by burnouts or voltage complaints from consumers. An effort was made to keep the initial transformer investment at a minimum. Because of the numerous problems resulting from operating under this procedure, some engineers have gone to the other extreme and deliberately use larger transformers than necessary to avoid these operating problems. Neither method has proven entirely satisfactory.

According to Ambrosius and Sarikas (6), rural distribution transformers on the Illinois Power Company lines are not enlarged or changed out except to protect the customer from inconvenience or disturbance. The reason for this procedure is the lack of use for small-sized transformers after replacement. On the other hand, if it does become necessary to remove a transformer, the largest economical size is selected as the replacement.

If an overloaded transformer is left in place until the consumer complains of low voltage, McDonald et al (18) report he probably has had poor service for some time, and he will be reluctant to expand his use of electricity. They are of the opinion that a method of changing out transformers which depends upon complaints of poor voltage or transformer failure is obviously unsatisfactory.

Demand meters

An ideal solution for determining transformer load is to have an ampere-demand or kilowatt-demand meter for each transformer according to the Rural Electrification Administration (21). In this way an exact value of demand would be obtained and there would be no question concerning the transformer load. Lockie and Book (17) state such a method is economically impractical as the meters would increase considerably the system investment.

Copper temperature indicators

Red-light signals and other devices operating on oil or copper temperature may be installed on transformers to indicate overloads. Lockie and Book (17) state that signal lamps will come on at loads approximating those at which changeouts to larger transformers are economical. An REA publication (21) points out that although such indicators have been successfully employed on urban systems, their use on rural lines is questionable. If they were employed in rural areas, the cost of patrolling to identify the overloaded transformers would be excessive. For this method to be successful on rural systems, some means other than patrolling would have to be devised as a means of locating the overloaded transformers.

Appliances served

A popular method of sizing rural distribution transformers is to group various combinations of load units and specify a size transformer to serve each group. For example, REA (21) has a classification with 13 groups of appliances, and the Flathead Electric Cooperative (13) uses a classification with nine groups. The latter classification is as follows:

Transformer rating kva.	Appliance group
1.5	Refrigerator, lights, small appliances
3.0	Refrigerator, lights, 1500-watt heater, small appliances
5.0	Range, 1500-watt water heater, lights, small appliances
5.0	Water heater, clothes drier, lights, small appliances
7.5	Range, 3-kw. water heater, clothes drier, ironer, etc.
10.0	Range, 9-kw. water heater, clothes drier, automatic washer, etc.
15.0	Range, dishwasher, 9-kw. water heater, clothes drier, washer, 3000-watt portable heater, ironer, etc.
15.0	Electric house heating plus assorted appliances
25.0	20-25 kw. connected house heating, range, 9-kw. water heater, clothes drier, washer, dishwasher, etc.

Although the system of loading transformers according to the appliances served is a popular one, it makes no provision for the extent to which the appliances are used; and many appliances, particularly those used in agricultural production, are omitted. Also, the classifications are arbitrary since few electric power suppliers have made detailed load studies on which to base their classifications.

Energy consumption

Demands on transformers are associated with the use of energy; and therefore, maximum demand is usually correlated with energy consumption.

Such correlations for multiple services have proved to be of great value in predicting transformer loads (21). These relationships are also often used for estimating the demands of single consumers. Probably the simplest way of using the relationship between energy consumption and demand is to arbitrarily associate a transformer size with a certain energy consumption. A relationship of this type used by the Flathead Electric Cooperative (13) is as follows:

Transformer size	Maximum energy consumption in a month
1.5	200
3.0	400
5.0	1,000
7.5	1,500
10.0	2,000
15.0	3,700
25.0	7,000

Another approach to the use of energy consumption in estimating demand was made by Ambrosius and Sarikas of the Illinois Power Company (6). They developed polynomial equations expressing maximum demand as a function of energy consumption from data acquired by metering the demands and energy consumptions of a number of consumers. In an effort to obtain greater accuracy, different equations were used for summer and winter energy consumptions. The equations developed were

$$\hat{Y} = 0.6861 + 2.4254X - 0.1779X^2 + 0.0041X^3$$

for winter and

$$\hat{Y} = 0.8492 + 2.80709X - 0.2492X^2 + 0.0074X^3$$

for summer,

where $\hat{Y}$ is the estimated 15-minute demand in kw. and X is the energy consumption for the 4-month summer or winter period in megawatt hours. The authors point out that the accuracy obtained with these equations when applied to rural transformers serving a single customer is not as acceptable as for a group of customers such as is normally served by an urban distribution transformer.

Strausser (24) has developed a more complex system of making use of energy consumption-demand relationships. Data as to the transformer number, size, voltage, consumer kw.-hr. consumption, a code for each class of consumer, and other information is fed into a digital computer. The load for each individual consumer is calculated by use of an equation developed specifically for the class of consumer. The computer program can handle six separate equations for different classes of consumers. As the individual loads are calculated, they are correlated by class until the last consumer load on a given transformer has been determined. The transformer loading is then calculated, taking into account diversity between consumers within a given class and also diversity between various classes of consumers. REA (21) points out that the diversified demand resulting from the individual demands of several consumers can quite accurately be correlated to energy consumption, but the same does not appear to hold true when only one consumer is served from a transformer.

Appliances served and energy consumption

In 1956 Altman and Jebe (3, 4) suggested the use of multiple regression equations in estimating the maximum demands of individual farms. Multiple regression techniques permit combining into a single prediction equation information on both appliances and energy consumption. To illustrate the methodology involved, coefficients for a multiple regression equation were calculated from data on a limited sample of 36 farms. The prediction equation obtained was

$$\hat{Y} = 3.398 + 1.233X_1 - 0.282X_2 + 2.096X_3 - 0.845X_4 + 0.857X_5 + 0.529X_6 + 0.00213X_7 + 5.714X_8 - 0.0321X_9 + 0.001799X_{10},$$

where $\hat{Y}$ was the estimated 30-minute annual demand of an individual farm in kilowatts and X_1 to X_{10} are, respectively, the number of ranges, water heaters, clothes driers, freezers, dairy water heaters, crop driers, stock waterers, feed grinders, heat lamps, and kw.-hr. used in the month with highest energy consumption. The negative regression coefficients generally occurred for appliances which used more than average energy in relation to their demand or for appliances with coefficients which had large standard errors. Although about 95 percent of the variation in maximum demands was associated with the variations in the above predictors for the 36-farm sample, the equation was not suitable for field application since the standard errors associated with many of the equation coefficients were large.

McDonald et al (18) state that this approach holds great promise of providing the elusive maximum demand on a single farm with reasonable accuracy and without individual demand metering. REA engineers in a staff report (22) commented favorably on the multiple-regression approach to the estimating of the maximum demands of farms and that further development of the method appears to be warranted.

OBJECTIVES

Several specialists in rural-distribution system design and operation are of the opinion that the multiple-regression-equation method of estimating maximum demands of farms for purposes of transformer loading has promise of being more satisfactory than presently used methods. Improved equations would result in benefits to both power suppliers and consumers.

The purpose of this study is the further development of the multiple-regression-equation method of estimating the maximum demands of rural consumers. The objectives are:

1. Development of procedures for collecting data to be used in determining coefficients of regression equations.
2. Selection of suitable equation models.
3. Investigation of the geographic applicability of demand estimating equations.
4. Comparison of the precision obtained in estimating demand with multiple-regression equations and other methods.

PROCEDURE

The demand of a consumer, Y, was assumed to be dependent upon a number of independent variables, X_1, X_2, . . ., such as the number or rating of the electrical appliances used and energy consumption. Equation constants and precision indices were calculated by multiple regressions technique from data collected especially for this purpose. Several procedures were tried for collecting the data used in these calculations and for eliminating insignificant independent variables from the equations. The equation constants and precision indices for a number of equation models were calculated and compared to determine the most suitable equation models.

Multiple Regressions

Snedecor (23) states that multiple regression seeks to fit a regression plane among the points such that the sum of the squares of the distances from plane to points is a minimum. According to Worthing and Geffner (30), the method of least squares, upon which the multiple regression procedure depends, does not indicate the best form or model of equation, whether linear or quadratic, or any other type, for the representation of given data. At most it yields the most probable values for the constants entering an equation of assumed form whatever that form may be. Volk (27) points out that multiple regression formulas are not restricted to variables having a dependent-independent relationship but may also be used to obtain a description in mathematical terms of the nature of the relationships within a group of inter-related variables. Any variable, therefore, which can be shown to be correlated with the maximum demand of a consumer may be useful in estimating the consumer's demand even though a known functional relationship does not exist between a particular variable and demand.

In the development of regression equations for this study it was necessary to select models for equations. Since there is no mathematical method for determining the best equation model, a number of different models were tried. Their suitability was determined by calculating equation coefficients and precision indices and comparing them with those of other models.

The computations required in calculating equation coefficients and precision indices have been presented in many statistical texts (23, 25, 27). The computational procedures suggested were usually designed for use with desk calculators. In this study, because of the large number of variables present, the use of desk calculators was not practical; and therefore the use of a digital computer was required.

Computer Programming

The basic computer program for multiple regression equations developed by the Iowa State University Statistical Laboratory and used for this study makes use of more than 1,800 machine instructions. The program used was for linear models of multiple regression equations of the type

$$\hat{Y} = C + b_1X_1 + b_2X_2 + \ldots b_nX_n$$

where $\hat{Y}$ is the estimated demand, C is a constant, and b_1, b_2, . . . b_n

are regression coefficients. The program permitted the calculating and the printing out of the standard errors of the regression coefficients, their t-values, and the estimated value of Y for each set of observations. By taking logarithms or raising the values for the variables to powers before entering the data into the computer, coefficients for logarithmic, polynomial, and exponential equation models were calculated.

The computer program did not eliminate predictors with small or uncertain contributions to the estimated demand. Two procedures were tried for eliminating these predictors. The first was the calculation of correlation coefficients between the predictors and demand. Predictors with low correlations with demand or small regression coefficients were eliminated. The other was the calculation of standard errors of the regression coefficients and the testing of the regression coefficients to determine if they could be established as being significantly different from zero by the "t" test of significance. Predictors were dropped if their regression coefficients were not significant at selected probability levels.

Collection of Data

A number of simultaneous observations of maximum demand, equipment used, and energy consumption are required in order to estimate the relationship between Y and X_1, X_2, ... Since many rural loads are seasonal in nature, continuous metering for a considerable period, preferably a year, is required to obtain maximum values of demand. Energy consumption information is usually available from the power supplier's records. Data on the other independent variables may be obtained by a mail survey or by visits to the consumers.

Data from power suppliers in three different geographic areas were used in this study. These were the Iowa Power and Light Company supplying data from their Adel, Iowa, district, the 10 REA-financed cooperatives comprising the Northwest Iowa Power Cooperative, and the Yellowstone Valley Electric Cooperative, Huntley, Montana. Because of the description length, the data from these three sources will be referred to as the Adel, NIPCO, and Montana data.

The procedures used in obtaining the data were different for each of the samples, and, therefore, each sample will be described separately.

Adel sample

The Iowa Power and Light Company was asked to cooperate in this study because they had in effect an optional rate which included demand as well as energy charges. This rate was available to rural residences and farms which used more than 1,800 kw.-hr. in 3-month periods. Thermal demand meters with a watthour register were used to determine the maximum 15-minute demands and energy consumptions.

Arrangements were made with this company to obtain the names, addresses, energy consumptions and demands of all of the consumers in their Adel district using the demand rate. The Adel district is in central Iowa and consists mainly of Dallas County. An information sheet (Appendix A) was mailed to each of 350 consumers with the request that the connected load data be completed and the form returned. Useful data from 157 consumers were returned by mail and another 40 were obtained by visits to the consumers' residences from a sub-sample of non-respondents. Appendix B is a listing of data found to be useful in predicting demands.

The demands in the Adel sample were recorded only to full kilowatts since the electric rate was based on whole kilowatts. The actual demand could be any value up to the next highest whole number. In tabulation, the values were arbitrarily raised to 0.5 kw. higher than the recorded values. Since demands ranged from 3 to 20 kw., errors between the tabulated and actual values could range from 16.5 to 2.5 percent.

The meters in the Adel data were read quarterly rather than monthly, the interval used by most power suppliers. To adjust the data to a monthly value an analysis of data obtained in an earlier study (4) showed that on the average approximately 40 percent of the quarterly energy consumption was used in the month with highest energy consumption. This factor was applied to the kilowatt-hours used in the quarter with highest energy use to approximate the highest monthly energy consumption.

NIPCO sample

The managements of the 10 REA-financed rural electric cooperatives comprising the Northwest Iowa Power Cooperative each agreed to purchase and operate 10 demand meters to obtain data for this study. The names and addresses of the NIPCO cooperatives are listed in Appendix C. Previous to the purchase of the metering equipment, investigations were made to determine appropriate metering equipment and a method of selection of consumers.

Metering equipment Two types of demand meters, thermal and mechanical, are available commercially and are suitable for metering demands for transformer loading studies. Thermal demand meters operate on the differential heating of two opposing bimetallic coils when a current is passed through them or adjacent heaters. They register about 90 percent of a steady applied load in 15 minutes from a cold start and 99 percent in 30 minutes. The mechanical demand meters indicate the demand that occurs in clock 15-minute periods. In both types of meters as used by power suppliers the indicating pointer pushes an idle pointer upscale. The idle pointer remains at the maximum position until it is manually reset. Since maximum demands rarely occur after a no-load period, similar values of demand are obtained with both meter types.

The meters selected by the NIPCO cooperatives were of the thermal type. These meters were installed at the consumer's service entrance in a test trough with two sockets so that the watthour meter used in billing could be continued in use. In order to be certain that the annual maximum demands were obtained, the demand meters were left in place for a year and were read and set quarterly.

Selection of consumers A detailed procedure for the selection of consumers was prepared in order to be certain of obtaining data on a variety of combinations of major appliances and energy consumptions. As each of the power suppliers metered 10 consumers, the selection guide as follows was based on this number.

Consumers 1, 2, and 3 used ranges and water heaters. One of the three also used a clothes drier. One of the three consumers used less than 1,000 kw.-hr. in the month with the maximum energy consumption for the past year.

Consumers 4, 5, and 6 used ranges but not water heaters. One of the three also owned a clothes drier, and one used less than 1,000 kw.-hr. in the month with the maximum energy consumption.

Consumers 7, 8, and 9 used water heaters but not ranges. One owned a clothes drier, and one used less than 1,000 kw.-hr. in the month with the maximum energy consumption.

Consumer 10 used a clothes drier but not a range or water heater.

At least two out of the ten consumers used more than 2,000 kw.-hr. in the month with the maximum energy consumption.

No consumer used less than 500 kw.-hr. in the month with the maximum energy consumption for the past year. This limitation was considered necessary to obtain maximum precision in estimating the demands of consumers with larger loads. Consumers with low energy consumptions usually require the minimum transformer size, which eliminates the transformer sizing problem for these cases.

The form used in reporting the demands, connected loads, energy consumption, and other information about each consumer is shown in Appendix D.

The demands and energy consumptions of 99 consumers of NIPCO were metered for the year ending June 30, 1959. Five of these consumers were eliminated because they moved during the year or because the data were incomplete or obviously inaccurate. Appendix E is a listing of data which were useful in estimating demands.

Montana sample

The Yellowstone Valley Electric Cooperative, Huntley, Montana, metered the demands of 100 consumers for 30-day periods during the winter of 1959-60. Mechanical-type demand meters were used. Consumers were selected on the same basis and the data sheets for connected loads were like those used for the NIPCO data. The data from this sample were used primarily in making comparisons with demands estimated by the NIPCO equations.

Since the demands of the consumers in the Montana sample were metered only for 30-day periods, the reported demands in some instances may not have been the highest for the year. To eliminate from the study some of the consumers with recorded demands considered to be other than annual maximum demands, consumers were dropped from the study if their energy consumptions during the demand metering periods were less than 60 percent of the highest energy consumption during any of the previous 12 monthly billing periods. The 60-percent figure was selected so as to eliminate some of the more questionable records from the sample and yet not to reduce the sample size excessively. This procedure reduced the number of consumers in this sample from 100 to 92. Appendix F is a listing of data which were used in calculating regression coefficients and precision indices.

RESULTS

The results obtained in this study in most instances are expressed as equation coefficients for various models of regression equations and their associated precision indices. The equations will be presented in the order in which they were developed.

Equations Based on Adel Data

The correlation coefficients were between the 23 predictors and demand. These coefficients are shown in Table 2. Data were available on the rating and number present for seven of the predictors. In these instances coefficients were calculated for both the ratings and the number present.

The correlation coefficients were used to eliminate predictors before the computation of regression coefficients for various equation models. Six predictors, food freezers, room heaters, grain-drier motors, conveyor motors, chicken brooders, and dairy water heaters, were eliminated on the basis of low correlation with demand. Where data on both the rating and the number present were available, the one with the highest correlation with demand was retained.

Coefficients for a multiple regression equation based on the remaining 17 predictors were calculated. The equation model used was

$$\hat{Y} = b_1X_1 + . . . + b_nX_n + C.$$

In consideration of their higher connected load, the seven double-oven ranges in the sample were assigned a weight of 1.3 times those with a

Table 2. Correlation coefficients between predictors and maximum demand for the Adel, Iowa, data--1956

Predictor	Correlation coefficient with demand
Ranges, No.	0.331
Portable roaster ovens, No.	-0.161
Water heaters, No.	0.154
Clothes driers, No.	0.500
Air conditioners, No.	0.184
Food freezers, No.	0.081
Food freezers, size in cu. ft.	0.051
Room heaters, No.	-0.027
Dishwashers, No.	0.140
Stock waterers, No.	0.139
Chicken brooders, No.	0.003
Heat lamps, No.	0.140
Grain-elevator motors, No.	0.154
Grain-elevator motors, hp.	0.214
Grain-drier motors, No.	0.002
Grain-drier motors, hp.	0.041
Conveyor motors, No.	0.083
Dairy water heaters, No.	0.046
Dairy water heaters, wattage	0.084
Milking machines, No.	0.042
Milking machines, hp.	0.144
Milk coolers, No.	0.188
Milk coolers, can size	0.155
Water pumps, No.	0.127
Water pumps, hp.	0.175
Welders, No.	0.142
Ironers, No.	0.125
Other heaters over 1,200 watts, No.	0.248
Other motors 1 hp. and larger, No.	0.360
Energy use, kw.-hr.	0.705

single oven. The resulting equation, Equation 1, was

$$\hat{Y} = 1.30X_1 - 0.60X_2 + 0.12X_3 + 1.64X_4 + 0.085X_5 - 0.33X_6 - 0.19X_7 + 0.021X_8 + 0.00074X_9 + 0.0014X_{10} - 0.012X_{11} + 0.0024X_{12} - 0.32X_{13} + 0.45X_{14} + 0.34X_{15} + 0.06X_{16} + 0.00168X_{17} + 3.60, \quad (1)$$

where $\hat{Y}$ is the estimated 15-minute demand of a consumer, and X_1 to X_{17} are, respectively, the number of ranges, portable roaster ovens, water heaters, clothes driers, air conditioners, dishwashers, stock-tank heaters and automatic cattle waterers, heat lamps, horsepower of motors on grain elevators, horsepower of motors on milking machines, can capacity of milk coolers, horsepower of motors on water pumps, number of welders, number of ironers, kilowatts of heating units uncategorized, horsepower of motors uncategorized, and the kw.-hr. used in the month with highest energy consumption.

The coefficient of determination, R^2, for Equation 1 was 0.74. R^2 is a measure of the success in estimating Y by means of multiple regression. The standard error of estimate, $s_{y.x}$, for this equation was 1.24 kw. $S_{y.x}$ is the estimation of the population parameter, $(\text{sigma})_{y.x}$, which is a precision index expressed in conventional units. If the errors are distributed normally, the absolute value of 68.27 percent of the errors will be less than the standard error of estimate, or in this case 1.24 kw.

With 197 observations in the sample, individual consumers had little effect on the equation coefficients; and consequently, the individual data used in deriving the coefficients may be used as a check on the precision of the equation. In using this technique the demands of each of the consumers were estimated by Equation 1 and the errors, the differences between the metered and estimated demands, were noted. The results are shown in Figure 1 where the errors are plotted against metered demands. As expected, about two-thirds of the errors were within one standard error, 1.24 kw., of the zero-error line.

It became apparent in making the estimations of demand that a number of predictors in the equation affected only slightly the estimated value of demand even though correlated with it. Those with small effect were X_3, X_5, X_6, X_9, X_{10}, X_{11}, X_{12}, X_{15}, and X_{16}. Coefficients for an equation with a reduced number of predictors were calculated from the Adel data for purposes of comparing coefficients with those of an equation developed from other data. This equation, No. 26, is presented in a later section.

Equations Based on NIPCO Data

The NIPCO data were used to explore the usefulness of a number of models of regression equations. Generally the equation models were selected on the basis of a knowledge of analytic geometry and relationships between demand and energy consumption. Equation models were modified by omitting predictors or making other changes in the basic models. Equation coefficients for a number of linear models were calculated initially; more complicated models followed.

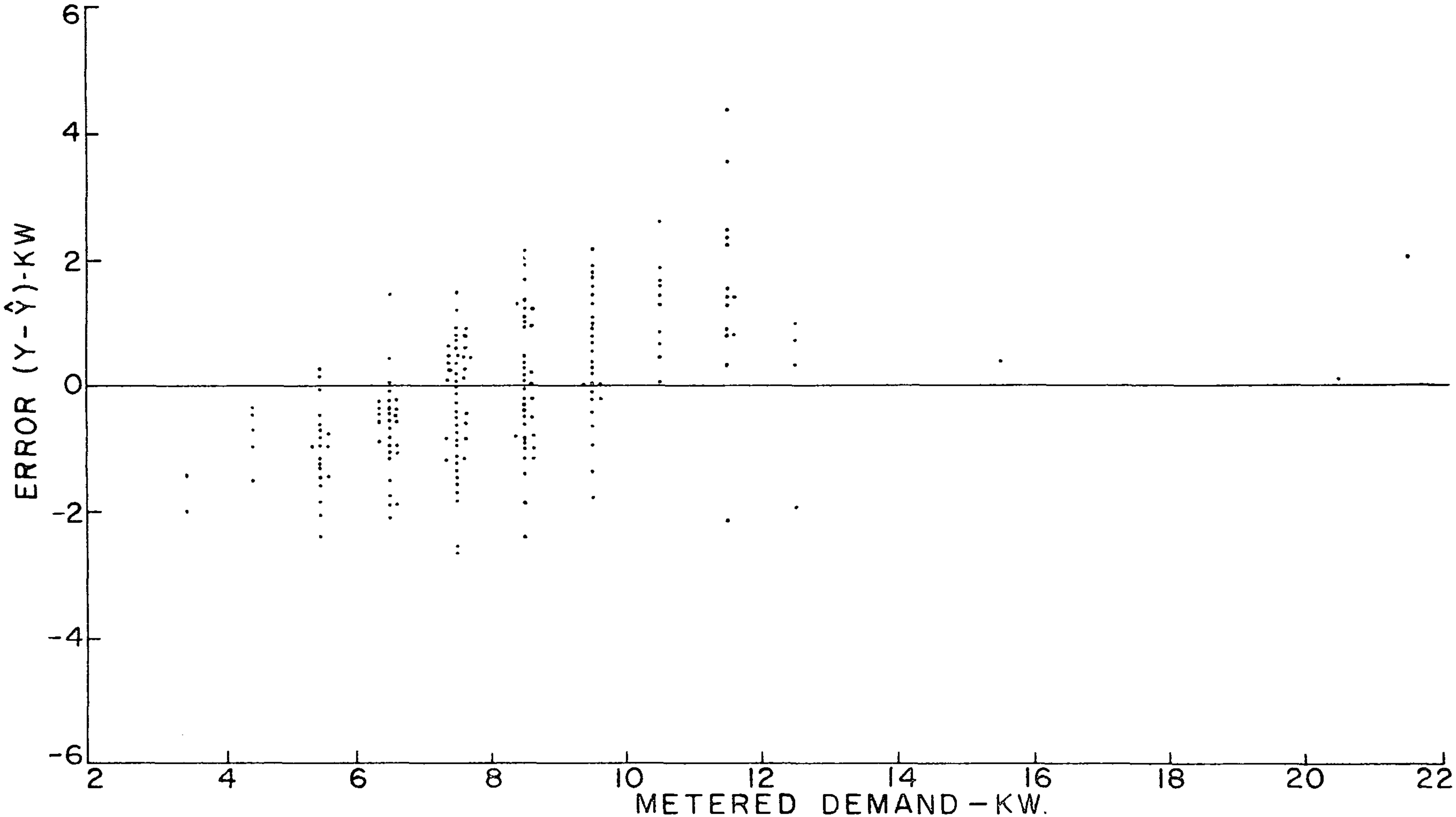

Figure 1. Errors in estimating demands of consumers in the Adel sample by Equation 1--1956

Linear equation models

The correlations between the predictors and demand and the regression coefficients with their standard errors for a linear model equation were calculated from the NIPCO data. The model of the equation used was

$$\hat{Y} = b_1X_1 + . . . + b_{27}X_{27} + C. \qquad (2)$$

Following the procedure of numbering the derived equations consecutively, this equation is designated Equation 2. The predictors with their letter designations, correlations with demand, multiple regression coefficients, standard errors of the regression coefficients, coefficient of determination, and the equation standard error of estimate of Equation 2 are shown in Table 3. As with the Adel data, the six double-oven ranges present in the sample were given a weight of 1.3.

Many of the predictors in Table 3 had low correlations with demand; some correlations were considered as being intermediate; and others were reasonably high. The regression coefficients of predictors with low or intermediate correlations with demand usually had standard errors larger than the regression coefficients. Coefficients and precision indices were calculated for four equations of the same model as Equation 2 except that the number of predictors was reduced by dropping from consideration groups of predictors having low or intermediate correlation coefficients. Table 4 shows a listing of the regression coefficients and precision indices of these equations, Equations 3 through 6. As the predictors were omitted, R^2 and $s_{y.x}$ changed only slightly which indicates that predictors with low correlation with demand or with large

Table 3. Correlations with maximum demand and regression coefficients for predictors in Equation 2 based on the NIPCO (Northwest Iowa Power Cooperative) data--1959

Predictor		Correlation with demand	Regression coefficient	Standard error of regression coefficient
X_1	Adults, No.	0.26	0.129	0.198
X_2	Children, No.	0.15	0.097	0.110
X_3	Ranges, No.	0.38	1.426	0.349
X_4	Roaster ovens, No.	0.33	0.216	0.542
X_5	Water heaters, No.	0.35	0.655	0.354
X_6	Clothes driers, No.	0.37	1.620	0.373
X_7	Air conditioners, hp.	0.23	0.088	0.371
X_8	Food freezers, cu. ft.	0.21	0.0203	0.0229
X_9	Room heaters, kw.	0.08	0.0575	0.329
X_{10}	Dishwashers, No.	0.20	0.237	0.747
X_{11}	Ironers, No.	0.10	0.156	0.505
X_{12}	House water pumps, hp.	-0.06	-0.226	0.739
X_{13}	Grain-elevator motors, hp.	0.24	-0.140	0.141
X_{14}	Grain-drier motors, hp.	0.03	0.163	0.191
X_{15}	Motors on silo unloaders and bunk feeders, hp.	0.37	0.528	0.101
X_{16}	Poultry and stock-tank heaters, kw.	0.43	0.639	0.329
X_{17}	Poultry brooders, kw.	-0.22	-0.222	0.337
X_{18}	Heat lamps, No.	0.17	0.027	0.0439
X_{19}	Dairy water heaters, kw.	0.37	0.386	0.548
X_{20}	Other motors 1 hp. or larger, hp.	0.39	-0.704	0.301
X_{21}	Milking machines, hp.	0.39	1.010	0.655
X_{22}	Direct-expansion bulk milk coolers, hp.	0.52	0.535	0.335
X_{23}	Other heaters larger than 1 kw., kw.	0.35	0.063	0.271
X_{24}	Can and ice-bank bulk milk coolers, hp.	0.11	-0.910	1.032
X_{25}	Farm water pumps, hp.	0.41	0.262	0.384

Table 3. (Continued)

Predictor		Correlation with demand	Regression coefficient	Standard error of regression coefficient
X_{26}	Welders, No.	0.38	-0.312	0.456
X_{27}	Energy consumption, kw.-hr. in maximum month	0.75	0.00114	0.000316
C	Equation constant		1.509	
R^2	Coefficient of determination		0.843	
$s_{y.x}$	Standard error of estimate, kw.		1.462	

standard errors of the regression coefficient contribute little to prediction equations.

Exponential equation models

The energy consumptions and demands of the 94 farms in the NIPCO sample were plotted on logarithmic graph paper. The points tended to follow a straight line indicating that an equation in the form

$$\hat{Y} = bX^m$$

may fit the data better than one of the form

$$\hat{Y} = bX + C.$$

By taking the logarithm of both sides of the equation,

$$\log \hat{Y} = \log b + m \log X$$

was obtained. With the equation in linear form, the constants b and m were calculated by the method of least squares. Upon substituting the

Table 4. Regression coefficients and equation standard errors and coefficients of determination for Equations 3 through 6 based on the NIPCO (Northwest Iowa Power Cooperative) data--1959

Predictor		Regression coefficients, Equation number 3	4	5	6
X_3	Ranges, No.	1.42	1.53	1.43	1.41
X_4	Roaster ovens, No.	0.33	-	-	-
X_5	Water heaters, No.	0.64	0.62	0.59	0.57
X_6	Clothes driers, No.	1.77	1.89	1.98	1.98
X_{13}	Grain-elevator motors, hp.	-0.15	-0.14	-0.11	-
X_{14}	Grain-drier motors, hp.	0.15	0.14	0.072	-
X_{15}	Silo-unloader motors, hp.	0.50	0.52	0.39	0.38
X_{16}	Stock-tank heaters, kw.	0.53	0.45	0.55	0.51
X_{18}	Heat lamps, No.	0.021	0.026	-	-
X_{19}	Dairy water heaters, kw.	0.37	0.28	-	-
X_{20}	Other motors, hp.	-0.64	-0.61	-	-
X_{21}	Milking machines, hp.	0.96	0.85	0.58	0.54
X_{22}	Direct-expansion bulk milk coolers, hp.	0.41	0.50	0.56	0.61
X_{23}	Other heaters, kw.	0.027	-	-	-
X_{24}	Can and ice-bank bulk milk coolers, hp.	-0.86	-0.62	-	-
X_{25}	Farm water pumps, hp.	0.47	-	-	-
X_{26}	Welders, No.	-0.23	-	-	-
X_{27}	Energy consumption, kw.-hr.	0.0013	0.0014	0.0012	0.0012
C	Equation constant	2.79	2.86	3.14	3.19
R^2	Coefficient of determination	0.83	0.82	0.81	0.81
$s_{y.x}$	Standard error of estimate, kw.	1.42	1.42	1.44	1.43

calculated values for b and m, one obtained the equation

$$\hat{Y} = 0.12X^{0.58}.$$

It was decided to use an exponent of 0.5 in the equation models that follow in place of 0.58 because the latter value was not precise since it is based on a sample and because the smaller value simplifies the calculations required in using the equations. A plot of the points and the two lines are shown in Figure 2. The small differences in the slopes of the two lines indicate that there is very little difference in the two exponents.

As indicated by the slopes of lines in Figure 2, an increase in energy consumption does not result in the same percentage increase in demand. Altman and Jebe (2) also found that the energy consumptions of farms and rural residential consumers usually increase at a faster rate than demands. Eight equation models were used in an effort to make use of the above and other relationships between energy consumption and demand.

Equations 7 and 8 The models used for Equations 1 through 6 allow positive values of demands to be predicted even though the energy consumption of the consumer is zero. Obviously there can be no demand if there is no energy consumption. From a practical application viewpoint this was not considered a weakness of the equations as they were intended for those consumers with energy consumptions of at least 500 kw.-hr. in one month. From an academic interest, however, models of exponential equations of a type that required the estimated demand be zero when energy consumption was zero were tried to see if they fitted

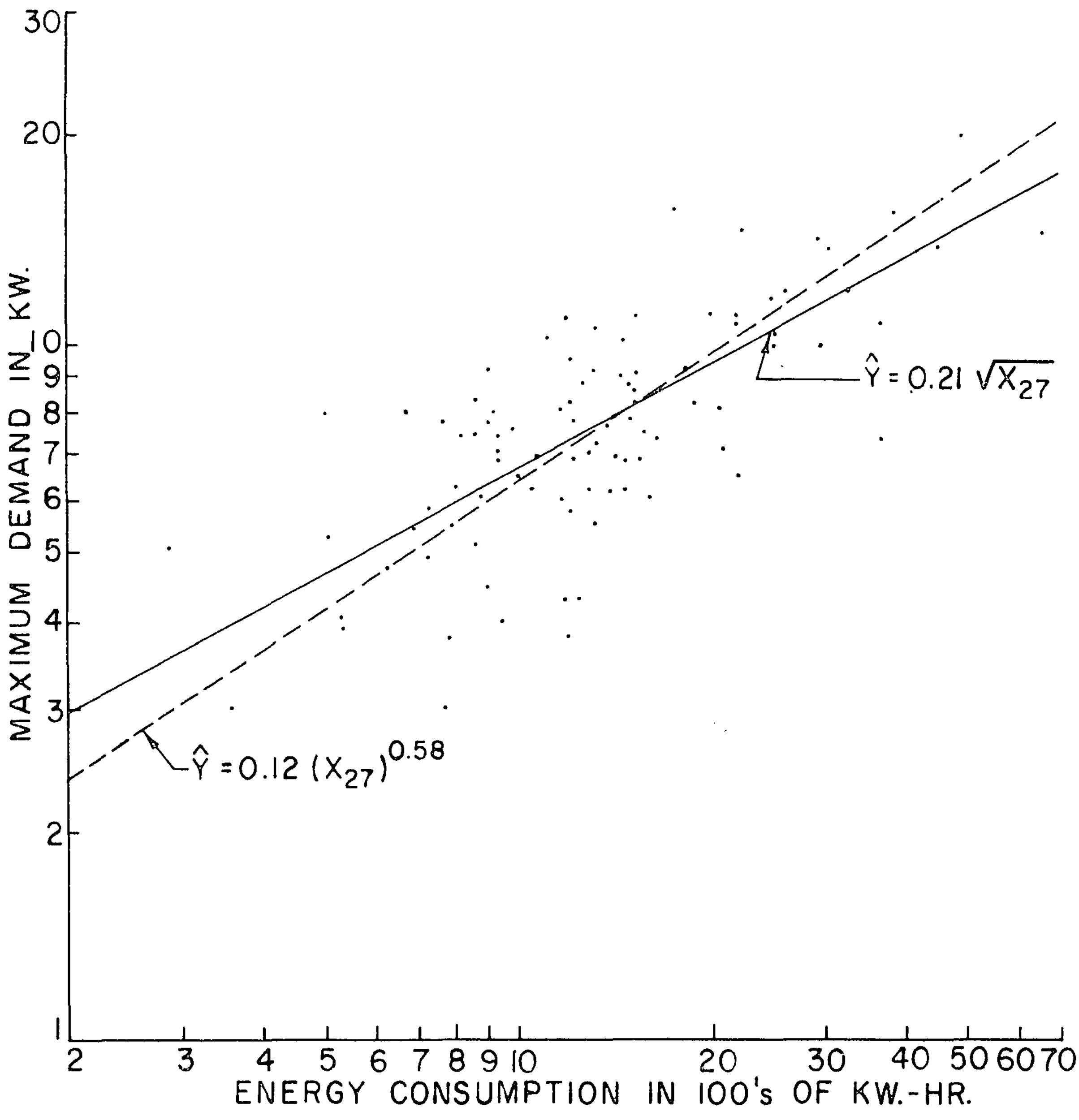

Figure 2. Regressions of metered maximum demands on energy consumption for the NIPCO (Northwest Iowa Power Cooperative) data--1959

the data better than linear models.

The first equation of this type, Equation 7, used the model

$$\hat{Y} = (bX_1 + . . . + b_{n-1}X_{n-1} + b_n)X_n^{\frac{1}{2}} \quad (7)$$

where X_n is energy consumption, X_1 to X_{n-1} the other predictors, and b_1 to b_n the regression coefficients for the predictors. Equation 8 had the same model as Equation 7 except that a constant term, C, was added and not multiplied by $X_n^{\frac{1}{2}}$. The model for Equation 8 was

$$\hat{Y} = (bX_1 + . . . b_{n-1}X_{n-1} + b_n)X_n^{\frac{1}{2}} + C. \quad (8)$$

This model was used to determine if a gain in precision resulted from not requiring the regression plane to pass through the origin. Table 5 shows the equation coefficients and precision indices for Equations 7 and 8.

The addition of the constant term increased the coefficient of determination by 5 percent and decreased the standard error of estimate by 0.15 kw. The precision indices indicate that Equations 7 and 8 do not fit the data as well as Equations 3 through 6.

Equations 9-14 In examining Equations 7 and 8, it was noted that multiplying the predictors by the square root of energy consumption increased the effect of the predictors on farms and rural residences with large energy consumptions relative to that with small energy consumptions. Logically the reverse may be true. For example, if a consumer had no major appliances and one were added, the major appliance maximum demand probably would occur at the time of the

Table 5. Equation coefficients and precision indices for Regression Equations 7 and 8 based on the NIPCO (Northwest Iowa Power Cooperative) data--1959

Predictor		Regression coefficients Equation number 7	8
X_3	Ranges, No.	0.024	0.025
X_5	Water heaters, No.	-0.0089	0.0032
X_6	Clothes driers, No.	0.026	0.038
X_{15}	Silo-unloader motors, hp.	0.0079	0.0088
X_{16}	Stock-tank heaters, kw.	0.0070	0.010
X_{21}	Milking machines, hp.	-0.0097	0.0042
X_{22}	Direct-expansion bulk milk coolers, hp.	0.0054	0.0096
X_{27}	Energy consumption, kw.-hr.	0.176	0.0688
C	Constant	0	3.26
R^2	Coefficient of determination	0.72	0.77
$s_{y.x}$	Standard error of estimate, kw.	1.70	1.55

consumer's peak demand. On the other hand, if a consumer added a major appliance to many other appliances, the diversity among the times of use of these may result in only small increases in the demand of the consumer as the result of the additional major appliance.

If the sum of the appliance predictors multiplied by their regression coefficients were divided rather than multiplied by the square root of the consumer's energy consumption, the effect of appliances on the demands of consumers with small energy consumption would be increased. To determine if this hypothesis results in more precise estimates of demands, coefficients were calculated for the following six equation models:

$$\hat{Y} = (b_1X_1 + . . . + b_{22}X_{22}) \frac{1}{\sqrt{X_{27}}} + b_{27}X_{27} + b_{27}'\sqrt{X_{27}} + C, \quad (9)$$

$$\hat{Y} = (b_1X_1 + . . . + b_{22}X_{22}) \frac{1}{\sqrt{X_{27}}} + b_{27}'\sqrt{X_{27}} + C, \quad (10)$$

$$\hat{Y} = (b_1X_1 + . . . + b_{22}X_{22}) \frac{1}{\sqrt{X_{27}}} + b_{27}X_{27} + C, \quad (11)$$

$$\hat{Y} = (b_1X_1 + . . . + b_{22}X_{22}) \frac{1}{\sqrt{X_{27}}} + b_{27}X_{27} + b_{27}'\sqrt{X_{27}}, \quad (12)$$

$$\hat{Y} = (b_1X_1 + . . . + b_{22}X_{22}) \frac{1}{\sqrt{X_{27}}} + b_{27}'\sqrt{X_{27}}, \quad (13)$$

$$\hat{Y} = (b_1X_1 + . . . + b_{22}X_{22}) \frac{1}{\sqrt{X_{27}}} + b_{27}X_{27}. \quad (14)$$

In these equations X_{27} is energy consumption, b_{27} and b_{27}' are, respectively, the regression coefficients for energy consumption and energy consumption to the one-half power, X_1 to X_{22} and b_1 to b_{22} are the other predictors and their regression coefficients, and C is an equation constant. Table 6 shows the calculated values of the equation coefficients and precision indices for regression equations based on these models.

The precision indices of Equations 9 and 10 show considerable improvement over those for Equations 7 and 8, and the standard errors of estimate are smaller than those of Equations 3 and 4. Equations 11 through 14 are not as precise as the others of this type because the

Table 6. Equation coefficients and precision indices for Regression Equations 9 through 14 based on the NIPCO (Northwest Iowa Power Cooperative) data--1959

		Regression coefficients					
		Equation number					
Predictor		9	10	11	12	13	14
X_3	Ranges, No.	57.2	56.2	52.7	49.2	42.8	76.1
X_5	Water heaters, No.	18.5	20.9	25.1	17.9	12.7	45.8
X_6	Clothes driers, No.	66.8	67.2	66.5	61.3	54.9	90.3
X_{15}	Silo-unloader motors, hp.	15.1	15.3	16.0	15.7	15.8	15.8
X_{16}	Stock-tank heaters, kw.	12.2	12.1	13.6	12.7	13.5	15.2
X_{21}	Milking machines, hp.	1.10	1.22	1.58	1.14	0.956	2.71
X_{22}	Direct-expansion bulk milk coolers, hp.	5.36	4.21	3.13	4.38	5.55	1.49
X_{27}	Energy consumption, kw.-hr.	-0.0014	--	0.0020	0.0006	--	0.0024
X_{27}'	Energy consumption, kw.-hr.	0.306	0.188	--	0.121	0.154	--
C	Constant	-4.18	-1.89	2.00	--	--	--
R^2	Coefficient of determination	0.82	0.81	0.78	0.80	0.80	0.75
$s_{y.x}$	Standard error of estimate, kw.	1.40	1.41	1.53	1.45	1.46	1.63

equation models did not provide for constant terms or, in the case of Equations 11 and 14, have a separate term for X_{27}'.

Equations 15-20 The models used for Equations 7 to 14 resulted in equation coefficients with magnitudes having little relationship to the magnitude of the expected demands. It would appear to be desirable to use equation models which are additive in form and, insofar as possible, which have equation coefficients of a magnitude similar to those that logically might be anticipated. Since it appeared that energy consumption to the one-half power fitted the NIPCO data more closely than energy consumption to the first power, equation models were next considered which included energy consumption to the first power and also to the one-half power. In all the previous equations milking machines and direct-expansion bulk milk coolers had relatively low regression coefficients and contributed little to the estimated demands; therefore, in Equations 15 to 20 these predictors and energy consumption to the first power were omitted in turn as shown in Table 7. The models used for Equations 15 to 20 were of the following general type:

$$\hat{Y} = b_1X_1 + \ . \ . \ . + b_{n-1}X_{n-1} + b_nX_n + b_n' \ \sqrt{X_n'} + C.$$

The precision indices in Table 7 show that Equations 15 through 18 fit the data as well as any of the other NIPCO equations. They also indicate that milking machines but not direct-expansion bulk milk coolers may be omitted from equations without loss of precision. The errors in estimating the individual demands by Equation 17 are shown in Figure 3.

Logarithmic equation models

The individual predictors in the multiple regression equations previously considered may not be completely independent of others. For example, ownership of a range is likely to be associated with ownership of a water heater and each of these predictors is associated with energy

Table 7. Equation coefficients and precision indices for Regression Equations 15 through 20 based on the NIPCO (Northwest Iowa Power Cooperative) data--1959

Predictor		Regression coefficients					
		Equation number					
		15	16	17	18	19	20
X_3	Ranges, No.	1.36	1.37	1.36	1.38	1.47	1.48
X_5	Water heaters, No.	0.39	0.44	0.39	0.44	0.36	0.31
X_6	Clothes driers, No.	1.87	1.90	1.86	1.89	1.97	1.96
X_{15}	Silo-unloader motors, hp.	0.37	0.37	0.37	0.37	0.35	0.35
X_{16}	Stock-tank heaters, kw.	0.50	0.48	0.47	0.45	0.37	0.37
X_{21}	Milking machines, hp.	0.45	0.45	-	-	-	-
X_{22}	Direct-expansion bulk milk coolers, hp.	0.90	0.74	0.95	0.79	-	-
X_{27}	Energy consumption, kw.-hr.	-0.00098	-	-0.00097	-	0.00067	-
X_{27}'	Energy consumption, kw.-hr.	0.20	0.11	0.20	0.12	0.09	0.15
C	Constant	-0.61	0.96	-0.68	0.88	1.06	-0.16
R^2	Coefficient of determination	0.82	0.82	0.82	0.82	0.79	0.79
$s_{y.x}$	Standard error of estimate, kw.	1.39	1.39	1.39	1.39	1.48	1.48

consumption. The statistical term for this association of predictors is multicollinearity (2). Multicollinearity in regression equations sometimes may be reduced by transforming the data. The following three equation models made use of logarithmic transformations:

$$\text{Log } \hat{Y} = b_1X_1 + \ldots b_nX_n + C, \tag{21}$$

$$\text{Log } \hat{Y} = b_1X_1 + \ldots b_{n-1}X_{n-1} + b_n \log X_n + C, \tag{22}$$

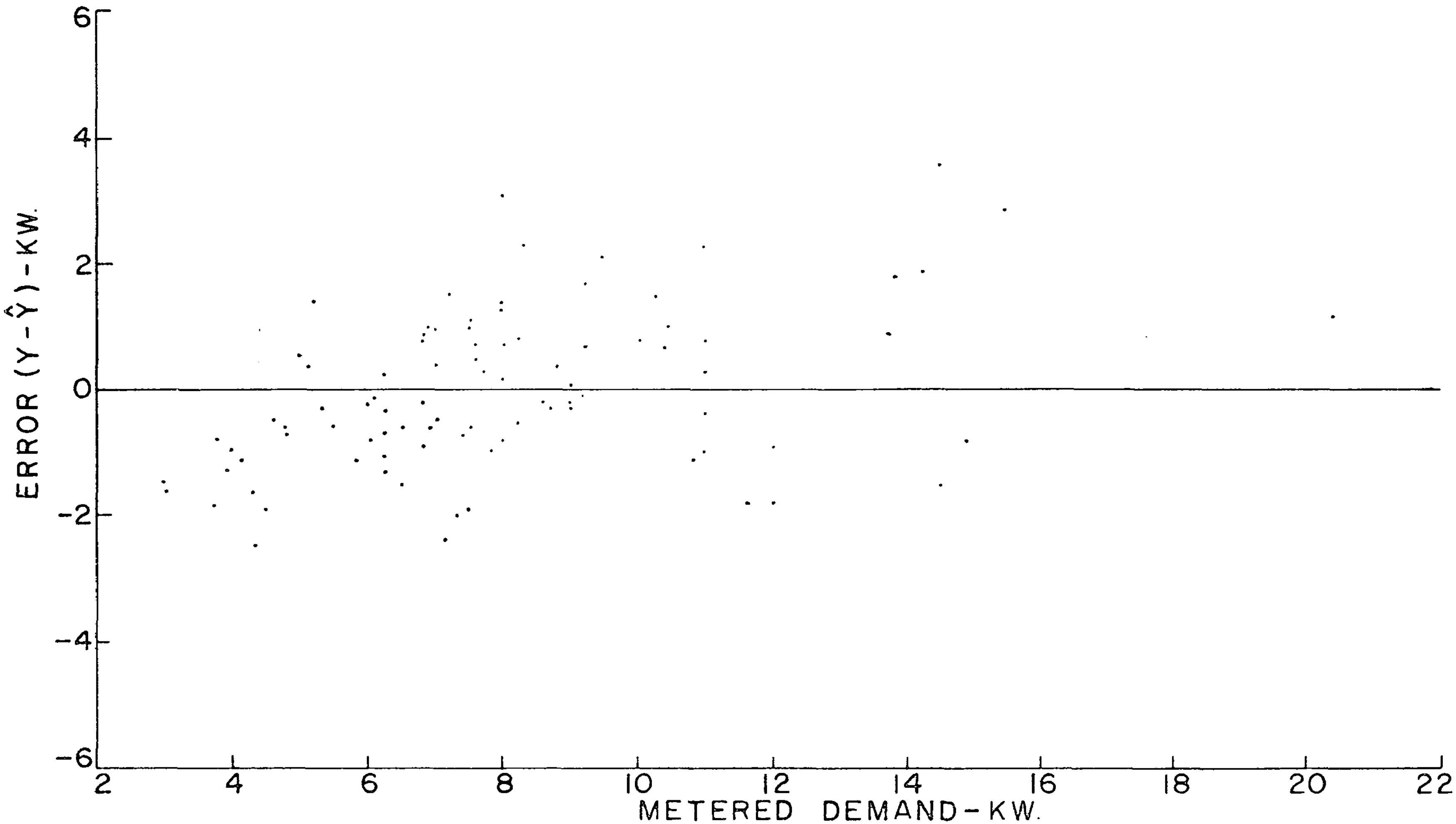

Figure 3. Errors in estimating demands of consumers in the NIPCO (Northwest Iowa Power Cooperative) sample by Equation 17--1960

$$\text{Log } \hat{Y} = b_1X_1 + \ . \ . \ . \ b_{n-1}X_{n-1} + b_n\sqrt{X_n} + C. \tag{23}$$

Equations 21 through 23 had standard errors of estimate of 1.73, 1.60, and 1.65 kw., respectively. Since these standard errors were well above the lowest obtained with other equation models, no further work was done with these equations.

Equations Based on Montana Data

The model used for Equation 24 based on Montana data was the same as for Equation 15, based on NIPCO data. This equation was additive in form with terms for energy consumption to both the first and one-half power. In calculating coefficients for this equation, energy consumption to the one-half power was dropped because the t-value of its regression coefficient was not significant at the selected level. Coefficients for a second equation of this type, Equation 25, were calculated with energy consumption to the one-half power substituted for energy consumption to the first power. Coefficients of Equations 24 and 25 are listed in Table 8. The numbering of the predictors was changed at this point to provide numbers in a logical order for double-oven ranges and quick-recovery water heaters.

The precision indices of Equations 24 and 25 show that Equation 24 fits the data slightly better than Equation 25, indicating that energy consumption to the first power is more useful in estimating the demands of the consumers in the Montana sample than energy consumption to the one-half power. The errors in estimating the individual demands by Equation 24, the more precise of the two equations, are shown in Figure 4.

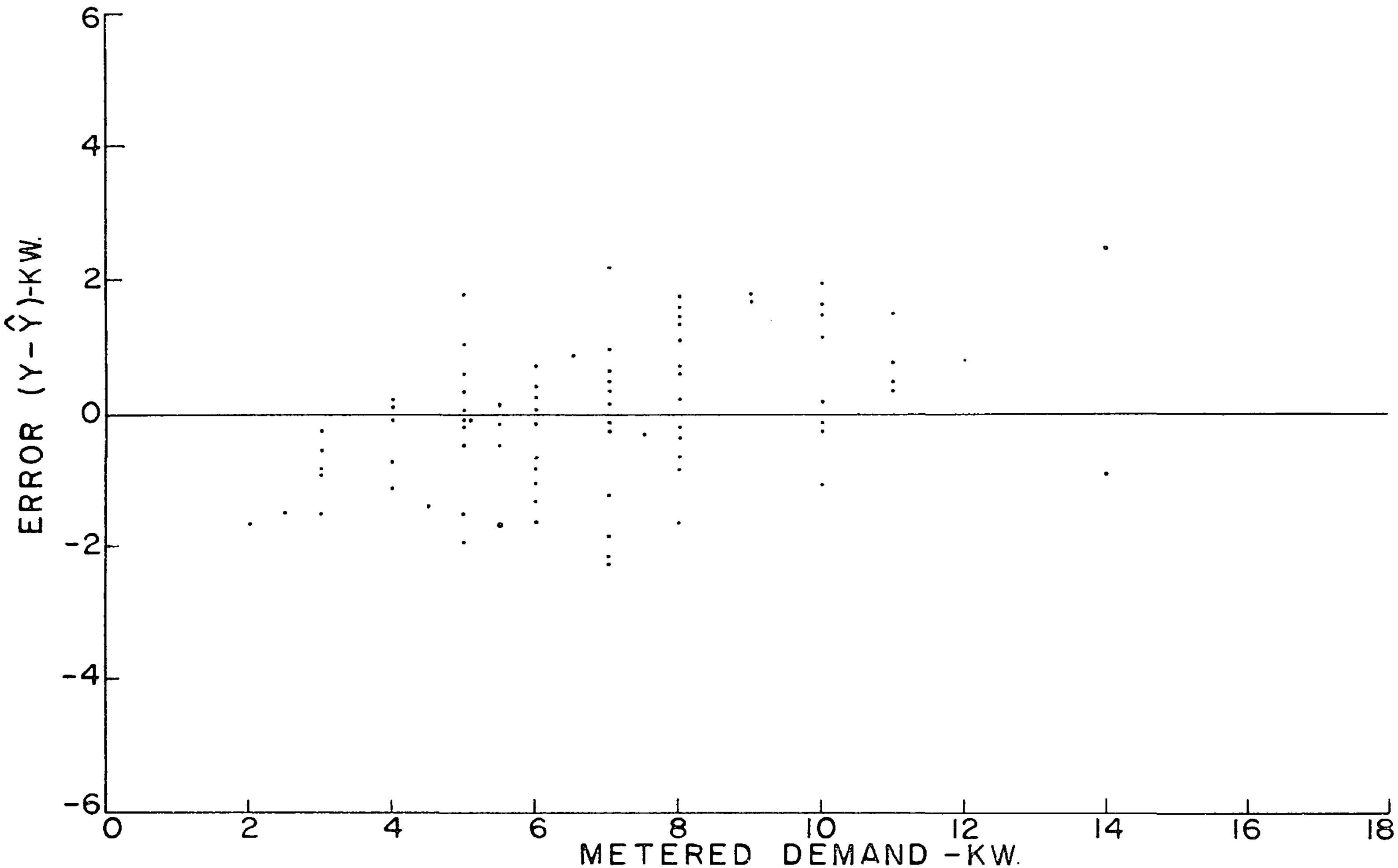

Figure 4. Errors in estimating demands of consumers in the Montana sample by Equation 24--1960

Table 8. Equation regression coefficients and precision indices for Regression Equations 24 and 25 based on the Montana data--1960

Predictor		Regression coefficients Equation number 24	25
X_1	Ranges, No.	1.12	1.09
X_2	Double-oven ranges, No.	1.32	1.35
X_3	Water heaters, No.	-0.308	-0.282
X_4	Quick-recovery water heaters, No.	1.05	1.68
X_5	Clothes driers, No.	1.84	2.06
X_6	Stock-tank heaters, kw.	-0.518	-0.282
X_7	Welders, No.	0.917	0.818
X_8	Energy consumption, kw.-hr.	0.00305	--
X_8'	Energy consumption, kw.-hr.	--	0.182
C	Constant	2.39	0.319
R^2	Coefficient of determination	0.817	0.798
$s_{y.x}$	Standard error of estimate, kw.	1.10	1.15

The procedure of eliminating predictors with small or uncertain contributions to demand on the basis of "t" tests was used with Equations 24 and 25. In using this method, all predictors for which data were available were used to calculate regression coefficients. The "t" test of significance was used to test the regression coefficients to determine if they could be established as being significantly different from zero. Predictors with t's not significant at the 30 percent probability level were dropped and new regression coefficients and t's calculated. The process of dropping predictors was repeated until all remaining regression coefficients were significant at the 30 percent probability level.

Use of Equations in Other Areas

The equation coefficients derived from data from one area may not be useful in estimating demands in another area since the populations from which the samples were selected may be different. If, however, equations from one area can be shown to be useful in estimating demands in another area, the populations of both areas are probably similar, and completely independent data are available for testing the equation and comparing coefficients. Also coefficients for equations may be calculated which make use of the combined data from both samples.

To determine if equations based on data from one locality have applicability in other areas, the demands of consumers were estimated by equations derived from data from other areas. The estimated and metered demands were then compared.

NIPCO and Adel samples

The demands of the individual consumers in the Adel sample were estimated using NIPCO Equation 6. Estimated demands averaged 7.84 kw. as compared to 7.67 kw. for the metered values. The equation standard error of estimate was 1.33 kw., a smaller value than the expected 1.43 kw. for Equation 6 when used on NIPCO data. This probably was attributable to the fact that the Adel data included most of the population while the NIPCO data were selected in a manner to cause variability. The populations from which the two samples were selected, however, appeared to be similar.

As a further check on the similarity of the populations, two

Table 9. Regression coefficients and precision indices for equations with the same model based on NIPCO, Adel, and the combined NIPCO-Adel data--Iowa, 1960

Predictor		Regression coefficients Equation number 6 NIPCO data	 26 Adel data	 27 Adel and NIPCO data
X_3	Ranges, No.	1.41	1.25	1.33
X_5	Water heaters, No.	0.57	0.23	0.38
X_6	Clothes driers, No.	1.98	1.68	1.78
X_{15}	Silo-unloader motors, hp.	0.38	0.45	0.39
X_{16}	Stock-tank heaters, kw.	0.51	-0.26	-0.07
X_{21}	Milking machines, hp.	0.54	-0.05	0.14
X_{22}	Direct-expansion bulk milk coolers, hp.	0.61	--*	0.50
X_{27}	Energy consumption, kw.-hr.	0.00119	0.00174	0.00158
C	Constant	3.19	3.35	3.32
R^2	Coefficient of determination	0.805	0.689	0.738
$s_{y.x}$	Standard error of estimate, kw.	1.432	1.202	1.290

*This predictor was not present in the Adel sample.

equations with the same model as for NIPCO Equation 6 were calculated from the Adel data and from the combined Adel-NIPCO data and the equation coefficients were compared. These equations are designated Equations 26 and 27. Their coefficients and those for Equation 6 are shown in Table 9.

The values of the coefficients for the predictors in the three equations were reasonably close except those for X_{16} and X_{21}, stock-tank heaters and milking machines. Upon calculation of t-values for the coefficients in the combined equation, it was found that b_{16} and b_{21}

were not significant at the 50 percent probability level. This indicated that the true values of the coefficients could have been zero and therefore agreement of the regression coefficients of the two equations should not have been expected. The coefficients for all of the other predictors were significant at the 5 percent probability level.

NIPCO and Montana samples

The data on each of the 92 consumers in the Montana sample were substituted into NIPCO Equation 18 in order to estimate their demands. Equation 18 was selected for this purpose because of its low standard error of estimate and the small number of predictors. The standard error of the estimated values was 1.30 kw., a smaller value than that of Equation 18 when applied to the data from which its coefficients were derived. It also appeared that the populations from which the NIPCO and Montana samples were selected were similar.

Equation Based on Combined Data

As indicated in the previous section, the demands of consumers in the Adel and Montana areas may be estimated by the equations with coefficients derived from the NIPCO data with almost the same precision as from equations based on data from the respective areas. For this to be true, the populations from which the three samples were selected must be similar. On the assumption that this was true, equation coefficients based on the combined data from the three samples were calculated. The model used was the same as for Equation 15. The equation coefficients and precision indices are shown in Table 10. The precision indices were

Table 10. Regression coefficients and precision indices for Equation 28 based on the combined data from the NIPCO, Adel, and Montana samples

Predictor		Regression coefficient
X_1	Ranges, No.	1.43
X_2	Double-oven ranges, No.	1.38
X_3	Quick-recovery water heaters, No.	2.40
X_4	Clothes driers, No.	1.83
X_5	Silo-unloader motors, hp.	0.39
X_6	Direct-expansion bulk milk coolers, hp.	0.42
X_7	Energy consumption, kw.-hr.	0.0017
C	Constant	3.28
R^2	Coefficient of determination	0.760
$s_{y.x}$	Standard error of estimate, kw.	1.234

an R^2 of 0.76 and a $s_{y.x}$ of 1.23 kw. The standard error of estimate is smaller than that of the most precise equation obtained from NIPCO data and larger than that of the best equations based on Adel and Montana data.

Predictors with regression coefficients not significant at the 5 percent level were dropped in the process of calculating equation constants. The coefficient for energy consumption to the one-half power was not significant at this level and therefore it was also dropped.

Comparison of Precision with Other Methods

The precision obtained by estimating demands on the basis of voltage complaints, copper-temperature indicators, and appliances served is difficult to evaluate. It is possible, however, to estimate closely the precision obtained by using energy consumption alone as the predictor of demand. The precision of estimation may be shown by the same indices used with the multiple regression equations.

Regression equations for demand on energy consumption were calculated for the NIPCO data. Equation models including energy consumption to the first power and also to the one-half power were chosen. The resulting equations were

$$\hat{Y} = 4.57 + 0.0023X \text{ and} \tag{29}$$

$$\hat{Y} = 0.154 + 0.21\sqrt{X} \tag{30}$$

where $\hat{Y}$ = predicted maximum demand and X = energy consumption in the maximum month. The coefficients of determination and the standard errors of estimate were, respectively, 0.56 and 0.58, and 2.07 and 2.02 kw. for Equations 29 and 30.

A polynomial equation similar to that used by Ambrosius and Sarikas (6) was fitted to the NIPCO data. The resulting equation was

$$\hat{Y} = 3.67 + 0.765X + 0.000232X^2 - 0.000463X^3 \tag{31}$$

where $\hat{Y}$ is the estimated demand and X is the energy used in the month with the highest energy consumption divided by 250. The coefficient of determination was 0.587 and the standard error of estimate 2.03 kw. These values are almost identical with those of Equation 30. The coefficient of determination for the most precise multiple regression equation using these data, NIPCO Equation 17, was 0.82. An additional 25 percent of the sums of squares of the deviations from regression were explained by including the predictors other than energy consumption. The standard error of estimate was reduced from 2.02 for Equation 30 to 1.39 kw. for Equation 17, a 31-percent improvement in the precision of estimate.

Confidence Intervals

If the multiple regression equations were used to estimate the maximum demands of consumers, the demands of about half of the consumers would be above the estimated values. The estimated values may be increased by an amount sufficient to reduce the number of demands above the estimated values to any desired percentage. This is done by calculating confidence limits or belts for the equations.

Snedecor (23) gives the following equation for calculating the confidence limits for simple regression equations when making predictions on individual events:

$$\text{Confidence interval} = \hat{Y} \pm (t)(s_{y.x}) \sqrt{1 + 1/n + x^2/\Sigma x^2}$$

where t is selected at the desired probability level, $s_{y.x}$ is the standard error of estimate, n is the number of observations in the sample, x^2 appearing in the numerator is the square of the deviation of the sample value from the mean, and Σx^2 is the sum of the squares of the deviations from the mean. Figure 5 shows the 95-percent confidence belt for Equation 29, the simple regression of demand on energy consumption and the only equation in this study for which the above expression may be used to calculate the confidence interval. Although not quite straight lines, the 95-percent confidence limits are approximately

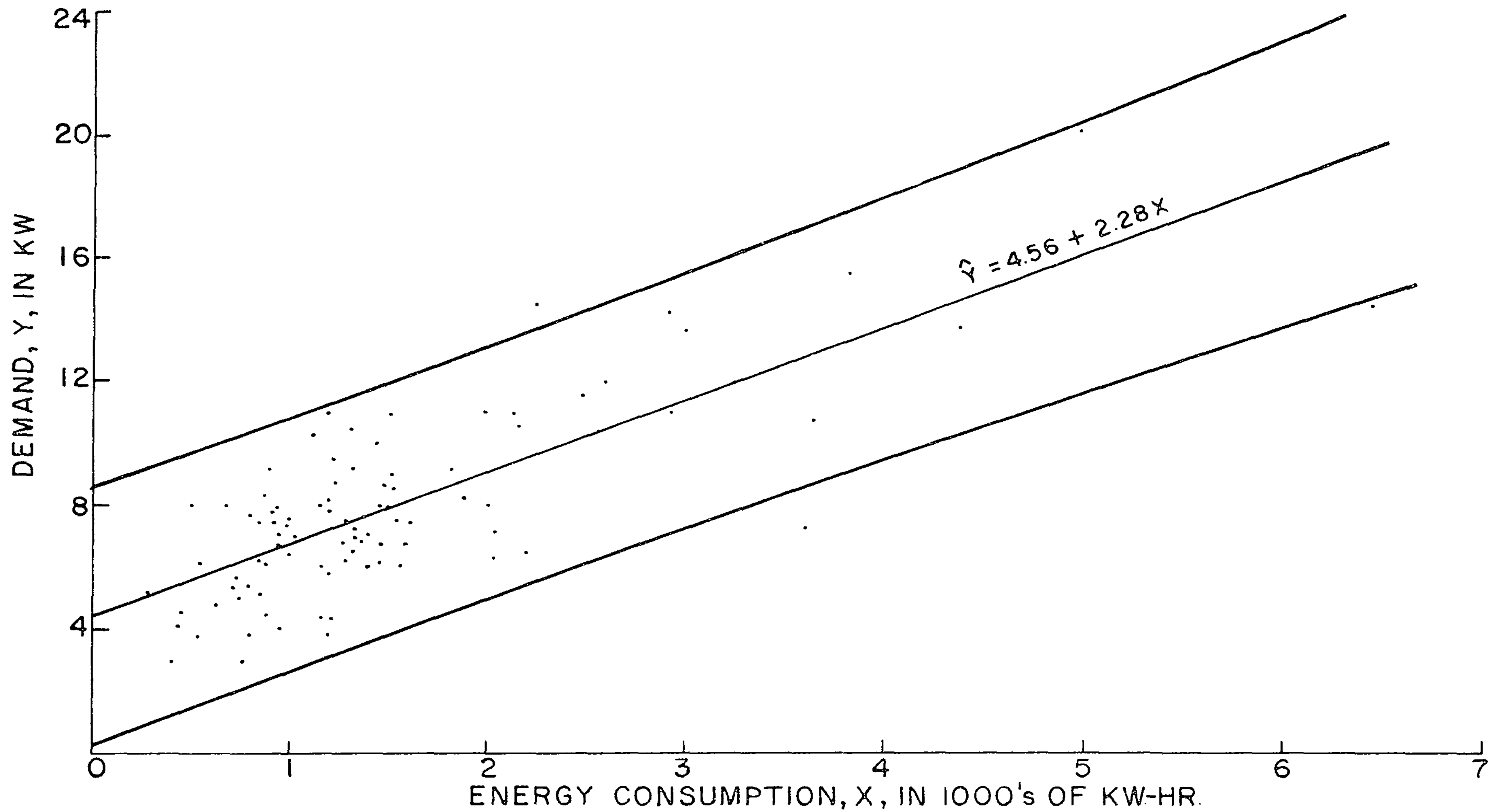

Figure 5. The 95-percent confidence belt for estimating the demand, Y, of an individual consumer by Equation 29 based on the NIPCO (Northwest Iowa Power Cooperative) data--1959

4.15 kw. above and below the estimated values.

The confidence limits for regression equations with a number of variables are more involved than those with two variables. When more than three independent variables are present, they cannot be shown graphically. Snedecor (23) shows the following expression for calculating the confidence limits for a multiple regression equation with three independent variables:

$$\text{Confidence interval} = \hat{Y} \pm (t)(s_{y.x})(1 + 1/n + c_{11}x_1^2 + c_{22}x_2^2 + c_{33}x_3^2 + 2c_{12}x_1x_2 + 2c_{13}x_1x_3 + 2c_{23}x_2x_3)$$

where $\hat{Y}$ is the estimated demand, the c's are multipliers (i.e. elements of the inverse matrix), and the x's are deviations of observed values from the means. In applying this equation to the NIPCO sample, the values of the products of the c and x terms and 1/n are small. Thus the confidence interval of the multiple regression equation is approximately equal to $\hat{Y} \pm (t)(s_{y.x})$.

Using the above equation the 95-percent confidence belt for Equation 17, the most precise of the NIPCO equations, was compared with that of Equation 28, the simple regression of demand on energy consumption. It was found that the confidence belt of the Equation 17 was only two-thirds of that of Equation 28 or a reduction of 2.78 kw. in the width of the 95-percent confidence belt.

DISCUSSION

The multiple regression equations studied gave more precise estimates of the maximum demands of consumers than other methods. However, the application of such equations by engineers to the problem of rural distribution transformers depends upon the following: a satisfactory procedure for collecting data, equation models that fit the observed data, and satisfactory instructions to the computing service for calculation of equation constants.

Collection of Data

The procedure used in the collection of data from the three samples generally was satisfactory. Even though the results show that equations calculated from the Adel and Montana data had low standard errors, it would have been desirable had the meters in these samples have been read to tenths of a kw. rather than to integral values of kw. The greater variability of the NIPCO data probably caused the relatively high standard errors of the equations using these data.

The continuous metering of the consumers for one year used with the NIPCO sample was the preferred metering period; however, in situations where the cost of metering each consumer restricted the sample size, the 30-day period used in the Montana sample appeared to be a satisfactory alternative. Consumers metered during periods of low energy consumption should be deleted from such data. Although the results obtained in this study do not prove this point, the precision of equation coefficients based on data collected by metering for an entire year should be greater than that obtained by metering for shorter periods.

The Adel data might have been more satisfactory for use in the development of multiple regression equations for estimating demands if the consumers had not have been on a demand rate. Personal visits revealed that a number of consumers went to considerable trouble or expense to keep demands low. Several used peak-limiting devices to disconnect the water heater when the clothes drier or range oven was in operation. Several others had no conception of demand or what it cost under the demand rate to use two major appliances at the same time.

There was a tendency in the Adel data for major appliances to appear in combinations. For example, most consumers had a range and a water heater; and therefore, a single predictor for the range-water heater combination would be almost as useful as a separate predictor for each appliance. Since the prediction equations developed were intended for use for consumers with one as well as for consumers with both of these appliances, the equation coefficients based on the Adel data may have a lower precision than would have occurred had major appliances not appeared in combinations.

The meters used in this study gave values of the maximum 15-minute demands which occurred during the metering period. Demand intervals of 15 minutes are more useful in the study of the thermal limitations of transformers than with voltage regulation limitations. Since voltage regulation is the controlling limitation on rural transformers, it would have been desirable to use demand meters with about 5-minute demand intervals if they had been commercially available.

The method used in selecting the NIPCO and Montana samples generally was satisfactory. Sufficient numbers of major appliances in the proper combinations were included for significant regression coefficients to be derived from a relatively small sample. A possible exception was the coefficient for water heaters. Apparently the high energy consumption of water heaters resulted in its contribution to demand being accounted for by the energy consumption term in the equation and therefore its regression coefficient was low. Probably a better sampling technique would have been to specify that a number of consumers have quick-recovery water heaters since these have higher demands than conventional water heaters.

If the data were being collected today, the method of selection of consumers would provide for a number of electrically heated houses, high-speed clothes driers, a greater number of quick-recovery water heaters, and perhaps several consumers with large motors. If the sample were selected from an area with summer-peak loads, provision would be made to include consumers with central or window-type air conditioners.

Equation Models

The linear models of multiple regression equations appeared to be the most satisfactory. The simpler forms of exponential equations with only the energy consumption term raised to a power also appeared to be satisfactory. Equation models that weighted predictors on the basis of energy consumption were not enough more precise than other models to justify their use.

Instructions to Computing Laboratory

Based on the experience of having a computing service calculate regression coefficients and precision indices for a number of models of equations, a list of instructions was developed so that the computing laboratory would have a simple procedure to follow in calculating the required information. This list proved satisfactory, and when used with suitable computer programs the required information was calculated with a minimum of manual work. The list of instructions to the computing service to accompany the data is as follows:

1. Calculate the multiple regression coefficients and the equation constant to fit the equation model

$$\hat{Y} = b_1X_1 + . . . + b_nX_n + C.$$

2. Calculate the t-value for each regression coefficient.

3. Drop from the equation all predictors whose regression coefficients have a t of less than 1.0.

4. Repeat 1 and 2. Drop from the equation those predictors whose coefficients have t's of less than 2.0.

5. Repeat 1 and 2 until all regression coefficients are significant at the 95-percent probability level.

6. Calculate the equation coefficient of determination, R^2, and the standard error of estimate, $s_{y.x}$.

7. Calculate the estimated value of maximum demand for each consumer in the sample.

It is important that Step 3 be executed as the standard errors of the regression coefficients change when predictors are dropped. If

Step 3 were omitted, a large number of predictors would be dropped at one time. Some of the predictors may have significant correlation coefficients after omitting some of those having little effect on demands.

Step 7 was included to allow a test of the accuracy of the data. Upon the return of the information from the computing service, the power supplier should compare the estimated with the metered demands to determine if considerable differences exist between the two. If large differences are found the equation coefficients may require recalculating after omitting those that appeared to be questionable. An example of this situation occurred with the Adel sample. The estimated demand of a farm was much lower than the metered value. A visit to the farm revealed that during the metering period a storm had blown a tree onto a line between farm buildings, producing a high-resistance grounding of the conductor. The added load was not enough to operate immediately the overcurrent protection at the service entrance. The resulting high demand at the service entrance was, of course, indicated by the demand meter.

RECOMMENDATIONS TO POWER SUPPLIERS

A power supplier contemplating the use of multiple regression equations in loading transformers should have available an equation which is suitable for his area and an accurate and up-to-date listing of the appliances used by each consumer. Energy consumption data are also required, but these usually already are available in the power supplier's office.

In using an equation to estimate the demands of consumers, the power supplier should give special consideration to those consumers with loads that may thermally overload transformers. Motors on hay and grain driers are examples of such loads as they may be in continuous operation. Transformers serving these loads must be large enough to meet thermal as well as voltage-regulation limitations. As a guide in choosing the transformer size, demands of consumers with these loads may be estimated by multiple regression equations; but the power supplier should load these transformers less heavily than when considering the more frequent limitations of voltage regulation. The remaining consumers with energy consumptions above 500 kw.-hr. in a month should be considered for the effect of their demands on voltage regulation. Transformers for the latter consumers may be sized to permit serving short-duration heavy loads.

Management should set a policy on the maximum permissible voltage drop in the transformers. As a guide REA (20) recommends that a 5-percent voltage drop be allowed in the transformer and service conductors with about 3 percent of this drop in the transformers. In a private communication H. R. Smith of the Rural Electrification Administration points out a more economical method is to increase the allowable voltage drop in the transformer and decrease the drop in the primary. If this procedure is followed, a 5-percent voltage drop in the transformer should be acceptable. A load of 200 percent of the nameplate rating will result in about a 5-percent voltage drop in most makes of the smaller sized distribution transformers. As a check on the thermal capability of transformers, reference to the ASA Guide (7) shows that 200-percent loads may be served for 60 minutes at a 30° C. ambient following a 50-percent load without serious loss of life expectancy. Safety factors on the thermal loading of the transformer result from the fact that the ASA Guide is considered conservative and from the estimated values being based on 15- rather than 60-minute demand intervals.

Safety factors on the voltage-regulation limitations of transformers also must be considered by the power suppliers. It should be realized that about half of the actual demands will be more than the estimated demands and some will be considerably above them. For example, with Equation 28 approximately 25 out of 1,000 consumers will have demands of more than 2.47 kw. above the estimated values. This does not mean, however, that all of the 25 consumers will have low voltage conditions as many of these high demands will occur when the distribution system is lightly loaded. Also these high demands normally will be nonrepetitive in nature and may occur only a few times a year; for example, only at those times when the range oven is on preheat and the clothes drier is in use.

In any given year it is expected that only about 10 percent of the consumers on a distribution system would have demands approaching 200 percent of the transformer rating. These consumers may be identified by use of multiple regression equations, and the kva. ratings of transformers serving them should be increased to approximately their estimated demands to allow for load growth.

The number of consumers with demands great enough to cause voltage-regulation problems should be quite small even if a safety factor is not applied. Until experience is gained in using multiple regression equations for transformer loading, however, a small safety factor probably should be used with the estimated demands to assure that only a few consumers will have demands of more than 200 percent of the transformer rating. The value of one standard error, about 1.23 kw. on the basis of Equation 28, is recommended as the value to add to the estimated demand. If this is done, no more than 0.25 percent of the actual demands should be more than 2.47 kw. above estimated values, and about 90 percent of these would be on transformers that are not excessively loaded. Using a safety factor greater than one standard error does not appear to be justified as an infrequent period of low voltage resulting from the consumer's own loads is a small price to pay for the savings resulting from using the overload capability of the transformer.

As a check on the accuracy of the estimated demands, a limited number of demand meters should be kept in operation by the power supplier. The use of these meters may result in identifying loads that cause estimated demands to differ markedly from metered demands. When sufficient data are collected from consumers with appliances not included in the equation, these data may be used in calculating coefficients for a new equation.

RECOMMENDATIONS FOR FURTHER STUDY

The equations based on data from three geographic areas gave useful estimations of demands in each of the areas. Data from other areas are required to define the geographic extent in which a particular equation may be reliable. Especially needed are data from areas where air conditioning causes peak demands to occur in summer. Also required are data from a number of consumers with electrically heated houses and other large loads.

It is possible that more precise estimations of demands may be made if consumers were divided into groups according to major enterprises such as dairy, poultry, cash-grain, and cattle farms and rural residences. To make such an analysis the total amount of data required would be considerably greater than used in this study.

The application of multiple regression equations to estimate the demands of consumers using less than 500 kw.-hr. per month should be investigated. It may be that the demands of such consumers are large enough to warrant the use of other than the smallest sized transformers.

Other models of equations should be studied to determine if they produce estimations of demand that fit the data more closely than those reported. Among the models that should be investigated are those using different functions of energy consumption as weighting factors for each appliance and those requiring that the data be transformed by other than a logarithmic transformation.

SUMMARY AND CONCLUSIONS

Presently used methods of determining the loading on distribution transformers in rural areas are either inaccurate or else expensive. As transformers are a costly part of the distribution system, large savings are possible through their proper loading. A determination or estimation of the maximum demand of each consumer is required in order that this may be done. In this thesis the use of multiple regression equations of demand on energy consumption and appliances served was proposed as a method of making estimates of the maximum demands of individual consumers.

Data were collected on the demands, energy consumptions, and appliances used by samples of consumers from two areas in Iowa and one in Montana. These data were used to develop procedures for selecting consumers, metering their demands, and calculating coefficients for regression equations. Coefficients and precision indices for 28 multiple regression equations were calculated. The coefficients and precision indices were compared with each other and with those of equations having only energy consumption as the predictor of demand.

The following statements are concluded from this study:

1. Data from approximately 100 consumers carefully selected to give a variety of energy consumptions and appliance ownership combinations are sufficient for use in deriving coefficients for multiple regression equations for estimating the demands of consumers.

2. Commercially available thermal and mechanical demand meters with approximately 15-minute demand intervals are satisfactory for

measuring demands.

3. The demands of the sample should be metered for as long a period as is practical, preferably up to a year. Metering of consumer demands for 30-day periods during seasons of high energy consumption is a satisfactory alternative.

4. The set of instructions for making the required calculations can be carried out by almost any computing service with a digital computer.

5. Only those predictors with coefficients having a high probability of being significant should be retained in multiple regression equations.

6. Predictors not used as a basis for sample selection are unlikely to have significant regression coefficients. The demands from these loads are included in one or more of the equation terms.

7. Linear equation models of the form

$$\hat{Y} = b_1X_1 + b_2X_2 + . . . + b_nX_n + C$$

are as precise as the more complicated equation models.

8. Coefficients of determination of about 80 percent can be expected for multiple regression equations.

9. Equation constants derived from the Adel, NIPCO, or Montana samples are suitable for use in the other two areas.

10. About a 30-percent improvement in the precision of estimating demands over the use of demand- and energy-consumption relationships can be expected when the predictors are energy consumption and appliances.

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APPENDIX A

IOWA STATE COLLEGE OF AGRICULTURE AND MECHANIC ARTS
AMES, IOWA

March 1957

ELECTRIC EQUIPMENT SURVEY

Name____

Address____

We would like very much to know the wattage or size of the equipment. If any sizes are not known, please make a check mark in the blank space if you have the appliances.

Home Do you have an electric

Range--single oven_____, double oven_____. Portable roaster oven____.

Water heater--gallons_____ or wattage_____.

Clothes drier--wattage_____. Air conditioner--horsepower_____.

Food freezer--cubic feet_____. Electric room heater--wattage____.

Dishwasher_____, wattage of heater_____, doesn't have heater_____.

Other home equipment with over 1200-watt heater rating or ½-hp. motor size______________________________________.

Farm Do you have a motor on

Grain elevator--horsepower_____
Grain drier--hp._____.
Hay drier--hp._____.
Silo unloader--hp._____.
Barn cleaner--hp._____.
Feed grinder--hp._____.
Feed mixer--hp._______.
Conveyor--hp._________.

If same motor is used on more than one of these loads, draw a connecting line between the proper items.

Is your farm equipped with electric

Stock water tank heaters--number_____, wattage_____.

Automatic cattle and combination cattle-hog waterers--number_____, wattage______.

Automatic hog waterers--number_____, wattage_____.

Chicken brooders--number_____, wattage_____.

Lamps used at one time for pig brooding--number_____.

Dairy water heater--wattage_____. Milking machine--motor size___.

Bulk milk cooler: direct-expansion____., ice-bank_____,
capacity gallons_____.

Can-type milk cooler--size_____. Milk house heater--wattage_____.

Water pump--motor hp._____. Welder_____.

Other farm equipment with over 1000-watt heater rating or ½-hp. motor size____.

APPENDIX B

Table 11. Data from the Adel, Iowa, sample used in the calculation of regression coefficients and precision indices[a]--1956

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	2386	5.5
2	1	0	1	1	1	0	2	0	45	0	0	6	0	0	1490	11.5
3	1	0	1	0	0	0	3	0	18	0	6	12	1	0	2513	7.5
4	0	0	1	1	0	0	2	4	0	0	0	6	0	0	1592	8.5
5	0	0	0	0	0	1	1	0	6	0	0	6	0	0	970	6.5
6	0	1	1	1	0	0	0	0	0	0	0	18	0	0	891	6.5
7	1	0	1	0	0	0	0	0	0	0	0	5	0	0	584	5.5
8	1	0	1	0	0	0	0	0	30	0	0	6	0	0	1531	9.5
9	2	0	1	1	1	0	1	3	0	0	0	6	0	0	1562	9.5
10	1	1	1	0	0	0	1	3	0	0	0	6	0	0	1130	6.5
11	1	0	0	0	0	0	1	8	0	6	12	9	0	0	2551	8.5
12	1	0	1	1	0	0	0	0	0	6	8	9	1	0	2056	12.5
13	1	0	1	0	0	0	0	4	18	12	7	4	0	0	2331	9.5
14	1	0	1	1	0	0	1	14	0	0	0	36	0	0	2436	11.5
15	1	0	1	0	0	0	1	1	0	0	0	21	1	0	1446	7.5

[a]Symbols are identified as follows: X_1, No. of ranges; X_2, No. of roaster ovens; X_3, No. of water heaters; X_4, No. of clothes driers; X_5, No. of air conditioners; X_6, No. of dishwashers; X_7, No. of stock tank heaters; X_8, No. of heat lamps; X_9, hp. x 6 of grain elevator motors; X_{10}, hp. x 12 of milking machines; X_{11}, No. of cans of milk coolers; X_{12}, hp. x 12 of water pumps; X_{13}, No. of welders; X_{14}, No. of ironers; X_{15}, kw.-hr. of energy consumption in maximum month; and Y, annual maximum demand in kw.

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
16	1	0	1	1	0	0	2	1	18	0	0	0	0	0	1452	7.5
17	1	0	1	1	0	0	0	2	18	3	0	8	0	0	1279	9.5
18	0	0	1	1	0	0	0	2	0	0	0	6	0	0	824	7.5
19	1	0	1	0	0	0	0	0	0	0	0	12	0	0	791	6.5
20	1	0	1	1	0	0	1	4	0	6	0	9	1	0	1694	8.5
21	1	0	1	1	0	0	4	18	18	0	0	12	1	1	1880	9.5
22	1	0	1	0	0	0	0	0	0	3	0	6	0	0	823	7.5
23	0	0	1	0	0	0	0	0	0	0	0	12	0	0	747	3.5
24	1	0	1	0	0	0	1	2	0	12	12	12	0	1	2483	10.5
25	0	0	1	0	0	1	0	8	0	4	8	13	1	0	1512	5.5
26	1	0	1	1	0	0	0	1	0	0	0	5	0	0	1137	8.5
27	0	0	1	1	0	0	0	0	0	6	6	10	0	0	1514	8.5
28	0	0	1	0	0	0	0	4	0	0	0	6	0	0	825	5.5
29	1	0	1	0	0	0	0	0	0	3	12	0	0	0	1942	8.5
30	2	1	2	0	1	0	0	0	18	0	0	18	0	0	1901	9.5
31	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1010	8.5
32	0	1	0	1	0	1	2	0	0	0	0	30	0	0	824	8.5
33	1	0	1	1	0	0	1	6	0	0	0	10	0	0	1277	11.5
34	1	0	1	0	0	0	0	0	0	0	0	6	0	0	1079	7.5
35	1	0	1	0	0	0	0	6	0	0	0	9	0	0	2054	8.5
36	1	0	1	0	0	0	1	0	0	0	0	30	0	0	840	7.5
37	1	0	1	1	0	0	0	3	0	0	0	0	0	0	1014	7.5
38	1	1	1	0	0	0	0	0	0	6	6	9	0	0	1189	5.5
39	0	2	1	0	0	0	0	0	0	6	7	12	0	0	861	4.5
40	0	0	1	0	0	0	0	0	18	0	0	18	1	0	1543	4.5

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
41	1	0	1	0	0	0	0	0	0	9	4	12	0	0	1180	7.5
42	0	0	0	1	0	0	1	8	30	0	0	12	1	0	1966	7.5
43	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1010	6.5
44	0	0	1	0	0	1	1	4	0	0	0	9	0	0	1779	8.5
45	2	1	2	1	0	0	1	0	18	6	6	0	0	0	1242	8.5
46	1	0	1	0	0	0	0	0	0	0	0	6	0	0	1388	8.5
47	1	0	1	1	0	0	1	0	0	9	0	4	0	0	1852	7.5
48	0	0	1	0	0	0	0	0	0	0	0	6	1	0	1384	4.5
49	1	0	0	0	0	0	0	0	0	6	0	4	0	0	639	5.5
50	1	1	1	1	0	0	0	0	0	0	0	6	0	0	1434	7.5
51	1	0	1	0	0	0	0	2	0	3	0	3	0	0	1458	8.5
52	1	0	1	0	0	0	0	0	0	0	0	9	1	0	1390	6.5
53	1	0	1	0	0	0	0	0	0	0	0	12	0	0	906	6.5
54	1	0	1	0	0	0	0	0	0	4	8	8	0	0	1850	9.5
55	1	0	1	0	0	0	2	19	0	0	0	18	1	0	1870	8.5
56	1	0	1	1	0	0	0	12	0	0	0	30	0	0	1694	8.5
57	1	0	2	1	1	0	0	0	12	0	0	6	0	0	1914	9.5
58	1	0	1	1	0	1	2	3	18	0	0	10	0	0	2837	7.5
59	1	0	1	0	0	0	0	0	0	0	0	4	0	0	1163	6.5
60	0	0	1	1	0	0	0	0	0	0	0	15	1	0	1473	9.5
61	1	0	1	0	0	0	3	8	12	0	0	0	0	0	2442	9.5
62	0	0	1	0	0	0	1	6	0	9	8	9	0	0	1337	8.5
63	1	0	1	0	0	0	0	6	0	0	0	6	0	0	1194	6.5
64	0	1	1	0	0	0	0	0	0	0	0	6	0	0	892	4.5
65	1	0	1	0	0	0	0	0	0	6	0	5	0	0	1360	7.5

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
66	1	1	1	0	0	0	0	0	0	0	0	6	0	0	2347	7.5
67	1	0	1	0	1	1	1	10	18	0	0	21	1	0	1795	10.5
68	1	0	1	1	0	0	1	4	0	9	12	12	0	0	2347	11.5
69	2	0	1	1	0	1	0	0	0	6	8	12	0	0	3103	12.5
70	1	0	1	0	0	0	0	0	0	0	0	24	0	0	1302	8.5
71	2	1	2	0	0	1	0	6	0	0	0	12	1	0	2400	9.5
72	1	0	2	1	0	0	0	12	0	0	6	18	0	0	2816	12.5
73	2	0	0	0	0	0	1	5	0	0	0	0	0	0	934	7.5
74	1	0	1	0	0	0	0	2	0	6	0	6	0	1	1053	8.5
75	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1160	7.5
76	1	0	1	0	0	0	0	6	0	0	0	4	0	0	1011	7.5
77	1	0	1	0	0	0	0	0	0	6	0	4	0	0	1122	6.5
78	0	0	1	0	0	0	1	0	0	4	6	4	0	0	1496	5.5
79	1	0	1	0	0	0	1	0	30	0	0	8	0	0	990	6.5
80	1	0	1	0	0	0	0	4	0	0	0	6	1	0	759	5.5
81	1	0	1	0	0	0	1	0	0	0	0	6	0	0	1130	6.5
82	1	0	1	0	0	0	0	0	18	0	0	6	1	0	1091	8.5
83	1	0	1	0	0	0	1	0	18	0	0	42	0	0	1153	8.5
84	1	0	1	1	0	1	2	0	0	6	0	10	0	0	2126	9.5
85	1	0	1	0	0	1	1	9	0	4	0	8	0	1	1918	7.5
86	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1015	6.5
87	1	1	1	1	0	0	2	0	0	6	0	12	0	0	1594	9.5
88	1	0	0	0	0	0	0	0	0	6	0	4	0	0	874	5.5
89	1	1	1	0	0	0	0	3	0	0	0	12	0	0	947	6.5
90	1	0	1	0	0	0	0	2	18	0	0	24	0	0	1440	8.5

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
91	1	0	1	0	0	0	1	1	18	0	0	18	0	0	1747	7.5
92	1	1	1	1	0	0	0	8	0	0	0	9	0	0	1506	10.5
93	1	1	1	0	0	0	0	16	0	9	0	6	1	0	1151	7.5
94	1	1	1	0	0	0	0	0	0	0	0	6	0	0	801	5.5
95	1	0	1	0	0	0	0	10	0	0	0	3	0	0	811	6.5
96	1	0	1	0	0	0	0	0	0	6	0	3	0	0	1258	6.5
97	1	0	1	0	0	0	1	1	0	0	0	12	0	0	1252	6.5
98	1	0	1	1	0	1	1	0	18	6	2	6	0	1	1601	8.5
99	1	0	1	0	0	0	0	30	0	0	0	27	1	0	1098	7.5
100	1	0	1	0	0	1	1	4	18	0	0	6	1	0	1462	7.5
101	1	0	1	0	0	0	4	0	0	0	0	6	0	0	1166	6.5
102	1	1	1	1	0	0	0	0	0	0	0	4	0	0	1511	8.5
103	1	0	1	1	1	0	0	8	0	0	0	3	0	0	1814	9.5
104	0	0	1	1	0	0	0	0	0	6	6	31	0	1	742	6.5
105	0	0	1	0	0	1	0	0	12	0	0	4	0	0	960	5.5
106	1	0	1	0	0	1	1	2	0	12	6	12	0	0	1291	6.5
107	1	0	1	1	0	0	1	0	3	0	0	6	0	0	1151	8.5
108	0	1	1	0	0	1	0	0	0	6	6	4	0	0	1273	5.5
109	1	0	1	0	0	0	0	3	0	0	0	24	0	0	1399	7.5
110	0	1	0	1	0	0	0	0	6	6	0	15	0	0	1513	7.5
111	1	0	1	1	0	0	1	0	0	0	0	6	0	0	1322	8.5
112	0	0	1	1	0	0	0	10	0	0	0	6	0	0	1290	10.5
113	1	0	1	1	0	1	1	0	0	0	0	4	1	0	7264	20.5
114	0	1	1	0	0	0	0	5	0	0	0	6	0	0	1153	4.5
115	1	1	1	0	0	0	0	0	0	0	0	5	0	0	716	7.5

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
116	1	0	1	0	0	0	0	3	0	0	0	4	1	0	770	7.5
117	1	1	1	1	0	0	1	20	0	0	2	6	1	0	2922	10.5
118	1	0	1	1	0	0	1	0	18	0	0	15	0	0	1167	11.5
119	1	0	1	0	0	0	2	0	0	0	0	4	0	0	1125	6.5
120	1	0	1	1	0	0	0	3	0	0	0	6	0	0	1847	8.5
121	2	0	2	1	0	1	1	3	72	0	0	24	1	0	4276	15.5
122	1	1	1	0	1	0	1	2	0	0	0	16	1	1	1098	7.5
123	1	0	1	1	0	0	1	8	0	6	0	9	1	0	934	6.5
124	1	0	1	0	0	0	0	6	0	0	0	0	0	0	1326	7.5
125	0	1	0	0	0	0	0	5	0	6	4	9	1	0	1218	4.5
126	1	0	1	0	0	0	1	4	0	0	0	12	0	0	1611	7.5
127	0	0	2	0	0	1	2	0	18	0	0	33	0	0	2325	6.5
128	0	0	1	1	0	1	1	0	18	0	0	12	0	0	1734	8.5
129	1	1	1	0	1	0	1	0	0	0	0	12	0	0	1916	7.5
130	1	0	1	0	0	0	1	6	18	0	0	12	0	0	1346	6.5
131	1	1	1	0	0	1	0	6	0	6	0	28	0	0	1415	7.5
132	1	1	1	1	0	0	0	6	18	9	0	0	0	0	1672	11.5
133	1	0	1	0	0	0	0	0	0	0	0	12	0	0	1866	9.5
134	1	1	1	1	0	0	1	0	30	0	0	6	0	0	1320	8.5
135	1	0	1	1	0	0	1	4	30	0	0	16	0	0	1809	9.5
136	1	1	1	0	0	0	1	4	0	0	0	12	0	0	1827	7.5
137	1	0	1	0	0	0	1	0	0	6	4	3	1	0	2266	9.5
138	1	0	0	1	0	0	0	0	0	9	6	9	1	0	1447	11.5
139	0	0	2	0	0	0	0	2	0	0	0	0	0	0	1807	8.5
140	1	0	1	0	0	0	0	0	0	0	0	12	0	0	1487	9.5

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
141	1	0	1	0	0	0	1	0	45	6	6	6	0	0	1699	7.5
142	1	0	1	0	0	1	0	26	0	0	0	3	1	0	1720	7.5
143	1	1	1	0	0	0	0	0	0	6	7	6	0	0	2454	10.5
144	0	1	1	0	0	0	1	12	0	0	0	6	0	0	2072	7.5
145	1	0	1	0	0	0	0	8	3	0	0	3	0	0	817	5.5
146	0	1	1	1	0	0	2	12	0	4	6	12	1	0	1962	9.5
147	1	0	1	0	0	0	1	5	18	4	6	4	1	0	1970	9.5
148	0	1	1	0	0	0	0	14	18	0	0	9	1	0	3882	9.5
149	1	0	1	0	0	0	0	2	0	6	0	0	0	0	1115	6.5
150	1	0	1	0	1	1	2	6	18	4	4	4	0	0	2869	9.5
151	2	0	1	0	0	0	2	2	0	0	0	6	1	0	1718	8.5
152	1	0	1	1	2	0	1	18	18	0	0	12	1	0	2945	12.5
153	1	0	1	0	0	0	0	0	0	0	0	0	0	0	442	6.5
154	1	1	1	0	0	0	2	9	0	0	0	12	1	0	1514	6.5
155	1	0	1	0	0	0	1	4	0	0	0	4	0	0	1202	8.5
156	1	0	1	1	0	0	1	2	18	0	0	6	0	0	1482	9.5
157	0	0	1	0	0	0	2	0	0	6	4	6	0	0	2300	5.5
158	1	1	1	0	0	1	1	6	18	6	10	4	0	0	2717	11.5
159	1	0	1	1	0	0	2	0	18	0	0	12	1	1	1602	10.5
160	1	0	1	1	0	0	1	4	0	6	4	3	0	0	1333	11.5
161	1	0	1	0	0	0	1	20	0	18	0	18	0	0	2019	11.5
162	0	0	1	0	0	0	0	16	0	4	6	6	0	0	994	5.5
163	1	1	1	0	0	0	1	5	0	0	0	18	0	0	1785	7.5
164	1	0	1	0	0	0	0	0	0	0	0	18	0	0	816	6.5
165	1	0	1	0	0	0	0	0	0	0	0	8	0	0	1419	9.5

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
166	1	0	1	0	0	0	0	4	18	0	0	18	0	0	1586	8.5
167	1	0	1	1	0	0	0	0	0	6	6	10	1	0	1683	10.5
168	1	0	1	0	0	0	1	0	18	0	0	6	0	0	450	5.5
169	2	0	1	0	0	0	1	0	0	6	4	5	0	0	1452	9.5
170	1	0	1	1	0	0	1	0	0	0	0	24	0	0	1865	10.5
171	1	0	1	0	0	0	2	3	0	4	0	24	1	0	2916	11.5
172	1	0	1	0	1	0	0	0	18	6	6	24	0	0	1428	8.5
173	1	1	1	0	0	0	0	0	0	0	0	10	1	0	922	7.5
174	1	1	1	1	0	1	1	2	0	0	0	5	1	1	938	7.5
175	1	0	1	1	0	0	0	6	0	9	4	0	0	0	1337	8.5
176	1	1	1	0	0	0	0	0	0	0	0	48	0	0	1255	8.5
177	1	0	1	0	0	0	0	0	30	6	0	18	1	0	1082	8.5
178	1	0	1	0	0	0	0	0	0	0	0	18	0	0	583	7.5
179	1	0	1	0	0	0	1	0	0	0	0	5	0	0	1284	7.5
180	0	0	0	1	0	0	0	10	18	6	9	24	0	0	1918	8.5
181	1	0	1	1	0	1	1	8	12	6	0	20	1	0	2485	11.5
182	1	0	1	1	1	1	1	7	12	0	0	16	0	1	1444	11.5
183	1	1	1	1	0	0	1	5	0	0	0	5	0	0	1723	10.5
184	1	0	1	0	0	0	0	0	0	0	0	5	0	0	1130	7.5
185	1	1	1	0	0	0	0	0	0	6	0	12	0	0	700	6.5
186	1	1	1	0	0	0	0	0	0	0	0	6	0	0	1154	7.5
187	0	0	1	0	0	0	1	0	0	0	0	6	0	0	1568	5.5
188	1	0	1	0	0	1	0	0	18	6	0	36	1	0	1190	6.5
189	1	0	1	0	0	0	0	18	0	9	8	12	1	0	2622	9.5
190	1	0	1	0	0	0	0	8	0	0	0	24	0	0	1212	9.5

Table 11. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
191	1	0	1	0	0	0	1	0	0	3	4	5	0	0	1219	7.5
192	1	1	2	0	0	0	0	25	18	4	0	6	0	0	1200	7.5
193	1	0	1	1	1	0	0	0	18	0	0	15	0	0	1106	8.5
194	1	0	1	0	0	0	1	3	18	0	0	5	0	0	1016	8.5
195	1	0	1	0	0	0	0	0	18	0	0	5	1	0	1170	7.5
196	1	0	1	1	0	0	0	0	0	9	8	24	0	0	4980	21.5
197	0	0	1	0	0	0	1	4	0	12	8	5	0	0	2304	5.5

APPENDIX C

Names and addresses of the electric distribution cooperatives in the Northwest Iowa Power Cooperative

Cherokee County Rural Electric Cooperative
Cherokee, Iowa

Ida County Rural Electric Cooperative
Ida Grove, Iowa

Nishnabotna Valley Rural Electric Cooperative
Harlan, Iowa

Harrison County Rural Electric Cooperative
Woodbine, Iowa

Monona County Rural Electric Cooperative
Onawa, Iowa

O'Brien County Rural Electric Cooperative
Primghar, Iowa

Plymouth Electric Cooperative Association
Le Mars, Iowa

Sioux Electric Cooperative Association
Orange City, Iowa

South Crawford Rural Electric Cooperative
Denison, Iowa

Woodbury County Rural Electric Cooperative
Moville, Iowa

APPENDIX D

UNITED STATES DEPARTMENT OF AGRICULTURE
FARM ELECTRIFICATION RESEARCH LABORATORY
IOWA STATE COLLEGE, AMES, IOWA

May 1958

Electric equipment survey form for transformer loading study--NIPCO area

Name of power supplier____

Name and address of farmer____________________________________

____

Adults living on farm--No._____. Children living on farm--No._____.

Family units on farm--No._____.

Record of 1958-1959 energy consumption and maximum demands

June_____kw.-hr.	Dec._____kw.-hr.
July_____kw.-hr.	Jan._____kw.-hr.
Aug._____kw.-hr.	Feb._____kw.-hr.
Sept.____kw.-hr.	March_____kw.-hr.
Oct._____kw.-hr.	April_____kw.-hr.
Nov._____kw.-hr.	May _____kw.-hr.

Maximum demand June - August__________________kw.-hr.

Maximum demand Sept. - Nov. __________________kw.-hr.

Maximum demand Dec. - Feb. __________________kw.-hr.

Maximum demand March - May __________________kw.-hr.

Appliance Data (Note date of addition or removal of appliances.)

House

Range--single oven____, double oven____. Portable roaster oven___.

Water heater--capacity, gal.____, wattage____. Quick recovery____.

Clothes drier--wattage_____.

Air conditioner--window type_____, central type_____, horsepower___.

Food freezer--number_____, cubic feet_____.

Electric room heaters--number_____, total wattage_____.

Dishwasher_____, wattage of heater, if any_____.

Ironer--wattage_____.

Water pump used solely for house--number_____, horsepower_____.

Other household equipment with over 1200-watt heater rating or

½-hp. motor size____.

Farm

Motor on:

Grain elevator--hp._____.

Grain drier--hp._________.

Hay drier--hp.__________.

Silo unloader--hp.______.

Barn cleaner--hp._____.

Feed grinder--hp._____.

Feed mixer--hp._______.

Conveyor--hp.__________.

(Indicate if same motor is used on more than one of above loads.)

Stock tank heaters--No._____, total wattage_____.

Automatic cattle or combination cattle-hog waterers--No._____, total wattage_____.

Automatic hog waterers--No._____, total wattage_____.

Automatic poultry waterers--No._____, total wattage_____.

Poultry hover brooders--No._____, total wattage_____.

Heat lamps used at one time--No._____, total wattage_____.

Dairy water heater--wattage_____.

Milk house heater--wattage_____.

Milking machine--hp._____.

Bulk milk cooler: direct-expansion_____, ice-bank_____; hp._____.

Milk cooler: can size_____, or hp._____.

Farm or additional water pumps--No._____, total hp._____.

Welder--amp. rating_____.

Other farm equipment with over 1200-watt heater rating or ½-hp.

motor size____.

APPENDIX E

Table 12. Data from the Northwest Iowa Power Cooperative sample used in the calculation of regression coefficients and precision indices[a]--1959

Farm No.	X_3	X_5	X_6	X_{13}	X_{14}	X_{15}	X_{16}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{27}	Y
1	0	0	1	0	0	0	0	18	0	0	4	0	0	6	1480	6.2
2	1	0	1	0	0	0	0.3	3	0	0	9	0	0	0	675	8.0
3	2	2	0	3	0	3	0.8	3	1.1	0	9	0	0	9	2930	14.2
4	1	0	0	0	0	0	0	10	0	0	6	0	0	4	1490	6.8
5	1	1	0	0	0	0	0	5	0	0	0	0	0	4	807	6.2
6	0	1	0	0	0	0	0	4	0	0	3	0	0	4	954	4.0
7	1	0	0	0	0	0	0	8	1.5	0	6	0	0	6	1329	7.2
8	1	1	1	3	0	0	1.6	0	0	0	0	0	0	0	906	7.8
9	0	1	1	0	0	0	3.0	24	0	0	0	0	0	0	4380	13.8
10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	774	3.0
11	1	1	0	0	0	0	1.3	0	0	0	0	0	0	0	726	5.8
12	0	1	1	0	0	5	0	0	0	0	4	0	0	3	2942	11.0
13	0	0	1	3	0	0	0	7	0	0	3	0	0	6	797	5.5
14	1	1	1	0	0	5	0	3	0	0	0	0	5.6	0	2159	11.0
15	1	1	0	0	0	0	1.9	4	0	0	0	0	0	0	1200	11.0

[a]Symbols are identified as follows: X_3, No. of ranges; X_5, No. of water heaters; X_6, No. of clothes driers; X_{13}, hp. of grain elevator motors; X_{14}, hp. of grain drier motors; X_{15}, hp. of silo unloader motors; X_{16}, kw. of stock tank heaters; X_{18}, No. of heat lamps; X_{19}, kw. of dairy water heaters; X_{20}, hp. of other motors 1 hp. or larger; X_{21}, hp. x 12 of milking machines; X_{22}, hp. x 12 of direct-expansion bulk milk coolers; X_{23}, kw. of other heaters; X_{24}, hp. x 12 of can or ice-bank milk coolers; X_{27}, kw.-hr. of energy consumption in the maximum month; and Y, annual maximum demand in kw.

Table 12. (Continued)

Farm No.	X_3	X_5	X_6	X_{13}	X_{14}	X_{15}	X_{16}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{27}	Y
16	1[b]	1	1	3	6	0	1.2	4	0	0	0	0	0	0	1530	11.0
17	1	0	0	0	0	0	1.2	10	0	0	0	0	0	0	1401	6.2
18	1	1	0	3	0	0	0.2	0	0	0	0	0	0	0	883	6.1
19	1	0	1	0	0	0	0	12	0	0	0	0	0	0	908	9.2
20	0	1	1	0	0	0	2.0	24	0	0	0	0	0	0	1524	8.6
21	0	1	0	3	0	0	2.3	16	0	0	0	0	0	0	3673	7.3
22	1	0	0	0	0	0	1.8	8	0	0	0	0	0	0	519	5.3
23	0	1	0	0	0	0	0	2	0	0	0	0	0	0	791	3.8
24	1	1	0	0	0	0	0	1	0	0	0	0	0	0	632	4.8
25	1	1	0	0	0	0	0	5	0	0	0	0	0	0	1333	6.5
26	1	1	1	0	0	0	0.2	5	0	0	6	0	1.3	0	1564	7.5
27	0	0	1	0	6	0	0.6	1	0	0	0	0	0	0	698	5.5
28	1	0	0	0	0	0	0.4	7	0	0	0	0	0	0	1166	8.0
29	1	0	1	0	0	0	0.5	0	0	0	0	0	0	0	920	8.0
30	0	1	1	0	0	0	0	7	0	0	6	0	0	0	1236	9.5
31	1	1	0	0	0	0	0	6	0	0	0	0	0	0	1220	5.8
32	1	1	1	5	0	0	0.8	12	0	0	0	0	0	0	3660	10.8
33	1	0	0	0	0	0	0	0	0	0	0	0	0	0	940	6.8
34	0	1	1	0	0	0	0.8	6	0	1	12	0	0	0	1300	6.2
35	1	0	0	0	0	0	1.2	0	0	0	0	0	0	0	900	4.5

[b]Double-oven range.

Table 12. (Continued)

Farm No.	X_3	X_5	X_6	X_{13}	X_{14}	X_{15}	X_{16}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{27}	Y
36	1	1	0	0	0	0	0	3	0	0	0	0	0	0	540	3.9
37	0	0	1	0	0	0	0.1	12	0	0	0	0	0	0	1240	7.8
38	0	1	0	0	0	0	0	0	0	0	0	0	0	0	860	5.1
39	0	1	1	0	0	0	0	6	0	0	6	0	0	0	1000	7.6
40	1	0	1	0	0	0	0	12	0	0	6	0	0	0	1830	9.2
41	0	1	1	0	0	0	0.5	2	0	0	0	0	0	0	1888	8.2
42	1	1	1	0	2	0	0.8	5	0	2	0	0	0	0	1106	10.3
43	1	1	1	0	0	0	0.2	2	0	0	0	0	0	0	1404	9.0
44	1	1	0	0	0	0	0	6	0	0	0	0	0	0	1087	7.0
45	1	1	0	3	0	22	1.5	0	0	5	0	0	0	0	1755	15.9
46	1[b]	1	0	0	0	0	2.0	7	0.8	1	3	0	0	12	2060	7.1
47	1	1	0	3	0	5	2.1	6	0	2	18	0	2.0	9	3817	15.5
48	0	1	1	3	0	0	0.2	10	0	0	0	0	0	0	1503	8.7
49	0	1	0	0	0	0	0.6	2	0	0	0	0	0	0	1252	4.3
50	1	0	1	0	0	0	0	0	0	0	6	0	0	9	1324	9.2
51	1	1	1	0	0	0	0	0	2.5	0	12	21	4.2	0	3030	13.7
52	1	1	0	0	0	0	0	2	0	0	0	0	0	0	1185	6.0
53	1	1	0	0	0	0	0	1	0	0	6	0	0	0	2195	10.6
54	1	1	0	0	0	0	0.3	12	0	0	6	0	0	6	1600	6.8
55	1	0	0	0	0	0	0	0	0	0	0	0	0	0	285	5.2
56	1	0	0	0	0	0	0.3	0	0	0	0	0	0	0	1390	7.6
57	0	1	0	0	0	0	0.1	0	0	0	5	0	0	0	1205	3.8
58	0	1	1	0	0	0	0	5	1.3	0	6	0	0	6	1210	8.2
59	0	0	1	0	0	0	0.5	0	1.5	0	6	0	0	6	1050	6.2
60	0	1	1	0	0	0	1.1	15	0	0	0	0	0	0	2550	10.4

Table 12. (Continued)

Farm No.	X_3	X_5	X_6	X_{13}	X_{14}	X_{15}	X_{16}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{27}	Y
61	1	0	1	0	0	0	0	3	0	0	0	0	0	0	1262	8.8
62	1	0	1	3	0	0	0.9	10	0	0	0	0	0	0	1541	9.0
63	0	1	1	0	0	0	0	10	0.5	0	6	0	0	4	1645	7.4
64	2	2	1	1	0	0	1.1	8	0	1	6	0	0	9	2604	12.0
65	2	1	1	2	0	0	1.6	10	0	0	12	24	0	0	3259	12.0
66	2[b]	2	1	5	0	0	1.5	6	0	0	0	0	0	0	2494	11.6
67	1[b]	1	1	0	0	0	0.8	5	0	0	0	0	0	0	2000	11.0
68	1[b]	1	1	0	0	0	0	0	2.5	6	12	36	0	0	6480	14.5
69	1	0	1	1	0	0	0	6	0	0	0	0	0	0	1460	8.0
70	1	1	0	3	0	0	1.1	4	0	0	9	0	0	0	1500	8.0
71	1	0	0	0	0	0	0.3	4	0	0	6	0	0	0	510	8.0
72	0	1	0	5	0	0	0	0	0	0	9	0	0	0	2050	8.0
73	0	0	1	5	0	0	1.3	6	0	0	0	0	0	0	1000	6.5
74	1	1	0	0	0	0	0	0	0	0	0	0	0	0	870	8.3
75	0	1	0	0	0	0	0	4	0	1	3	0	0	0	1600	6.0
76	1	0	0	0	0	0	0	10	0	0	0	0	0	0	950	7.0
77	1	1	1	0	0	0	1.5	10	0	0	0	0	0	0	2230	14.5
78	1	1	1	0	0	0	1.5	5	1.5	0	12	78	2.0	0	5004	20.4
79	0	1	1	0	0	0	0	0	0	0	0	0	0	0	822	7.5
80	0	0	1	0	0	0	0	10	0	0	0	0	0	0	942	7.5
81	0	0	1	0	0	0	0	5	0	0	0	0	0	0	360	3.0
82	0	1	0	0	0	0	0	10	0	0	0	0	0	0	1392	6.9
83	1	0	0	0	0	0	0	10	0	0	0	0	0	0	2194	6.5
84	1	1	1	0	0	0	0	10	0	0	0	0	0	0	1452	10.0
85	1	1	1	0	0	0	1.3	0	0	0	0	0	0	0	1321	10.5

Table 12. (Continued)

Farm No.	X_3	X_5	X_6	X_{13}	X_{14}	X_{15}	X_{16}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{27}	Y
86	1	1	0	0	0	0	0.8	3	0	0	9	0	0	0	1340	7.0
87	1[b]	0	0	1	0	0	0.1	1	0	0	0	0	0	0	540	4.1
88	0	0	1	0	0	0	0	2	0	0	4	0	0	0	490	4.6
89	0	1	1	0	0	0	0.1	2	0	0	0	0	0	0	1240	6.9
90	1	0	1	0	0	0	0	8	0	0	6	0	0	0	780	7.7
91	1	1	1	0	0	0	0.1	0	0	0	0	0	0	0	870	7.5
92	1	0	0	0	0	0	0.8	4	0	0	0	0	0	0	1190	4.3
93	0	1	0	0	0	0	0	0	0	0	0	0	0	0	740	5.0
94	1	1	0	0	0	0	0.1	3	0	0	0	0	0	0	1300	7.6

APPENDIX F

Table 13. Data from the Montana sample used in the calculation of regression coefficients and precision indices[a]--1960

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1000	7.0
2	1	0	1	0	0	2	1	22	0	0	0	10	1	0	1270	8.0
3	0	1	1	0	0	0	0	15	0	0	0	0	0	0	1448	7.5
4	1	0	1	0	1	0	1	17	0	0	0	0	0.75	0.50	1248	10.0
5	1	0	1	0	0	0	1	18	0	0	0	8	0	0	1317	7.0
6	1	0	1	0	0	0	0	14	0	0	0	0	0.75	0.50	1080	7.0
7	1	0	1	0	0	2	1	36	1.35	0	0	0	0	0	1100	5.0
8	0	1	1	0	0	0	0	16	0	0	0	0	0	0	1206	7.0
9	1	0	1	0	0	0	0	18	0	0	1	2	1	0.33	1437	6.0
10	0	1	0	1	0	3	0	0	0	0	0	1	0	0.33	2576	10.0
11	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1121	6.0
12	1	0	1	0	0	4	0	22	0	0	0	0	0	0	1320	7.0
13	2	0	2	0	0	1	0	16	1.35	0	0	0	0.75	0.50	2000	8.0
14	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1038	8.0
15	1	0	0	0	0	4	1	20	0	0	0	0	0	0.50	1910	9.0

[a]Symbols are identified as follows: X_1, No. of single-oven ranges; X_2, No. of double-oven ranges; X_3, No. of conventional water heaters; X_4, No. of quick-recovery water heaters; X_5, No. of clothes driers; X_6, kw. of poultry and stock tank heaters; X_7, No. of welders; X_8, cu. ft. of food freezers; X_9, wattage of room heaters; X_{10}, No. of dishwashers; X_{11}, No. of ironers; X_{12}, No. of heat lamps; X_{13}, hp. of milking machines; X_{14}, hp. of farm pumps; X_{15}, kw.-hr. of energy consumption in maximum month; and Y, annual maximum demand in kw.

Table 13. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
16	1	0	1	1	0	0	1	0	0	0	0	0	0.33	0	1640	10.0
17	1	0	0	1	0	0	0	11	0	0	0	0	0	0	1180	8.0
18	0	1	0	1	0	0	0	17	0	0	0	0	0	0	1550	11.0
19	1	0	0	1	0	0	1	15	1.35	0	0	5	0.50	0	1540	11.0
20	1	0	1	0	1	0	0	18	0	0	0	0	0	0	1780	11.0
21	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1130	10.0
22	1	0	1	0	1	1	1	18	1.35	0	0	0	0	1	1670	11.0
23	1	0	1	0	1	2	0	15	1.30	0	0	0	0	0	1630	10.0
24	0	1	1	0	1	4	0	36	0	0	1	0	0.75	0.75	2731	14.0
25	1	0	1	0	1	0	0	18	2.70	0	0	0	0	0	1300	10.0
26	1	0	1	0	1	0	0	13	0	0	0	0	0	0	1655	10.0
27	1	0	1	0	1	1	0	20	0	1	0	5	0	0	1400	8.0
28	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1700	11.0
29	1	0	0	0	0	0	0	20	0	0	0	0	0	0	480	5.0
30	1	0	0	0	0	0	0	7	0	0	1	0	0	0	400	4.0
31	0	1	0	0	0	0	0	20	0	0	0	0	0	0.33	700	6.0
32	1	0	0	0	0	0	0	25	1.25	0	0	0	0	0	889	8.0
33	0	1	0	0	0	0	0	21	0	0	0	0	0	0	750	5.5
34	1	0	0	0	0	1	0	16	0	0	0	0	0	0	660	5.0
35	1	0	0	0	0	0	0	10	0	0	0	0	0	0	350	5.0
36	1	0	0	0	0	0	0	11	0	0	0	0	0	0.50	700	6.0
37	1	0	0	0	0	0	0	18	0	0	0	0	0	0	560	6.0
38	1	0	0	0	0	0	0	15	0	0	0	0	0	0	530	5.0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	646	5.0
40	1	0	0	0	0	0	1	18	0	0	0	0	0	0.50	650	8.0

Table 13. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
41	1	0	0	0	0	0	0	12	2	0	0	0	0.50	0.50	1085	7.0
42	1	0	0	0	0	0	1	20	2.70	1	1	0	0	0	710	7.0
43	1	0	0	0	0	0	0	17	1.50	0	0	1	0	0	584	5.5
44	1	0	0	0	0	0	0	15	0	0	0	0	0	0.50	530	5.0
45	1	0	0	0	0	0	0	18	0	0	0	0	0	0	640	5.0
46	1	0	0	0	0	0	0	20	0	0	0	0	1	0	670	6.0
47	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1030	7.0
48	1	0	0	0	1	0	0	16	1.35	0	0	0	0	0	641	6.0
49	1	0	0	0	1	0	0	18	0	0	0	0	0	0	469	7.0
50	2	0	0	0	1	0	0	30	1.35	1	1	0	0	0	900	7.0
51	1	0	0	0	1	0	0	0	0	0	0	0	0	0	933	9.0
52	1	0	0	0	1	0	0	20	0	0	0	0	0	0.50	650	6.0
53	0	1	0	0	1	0	1	15	0	0	0	0	0.50	0	600	8.0
54	1	0	0	0	1	0	0	12	0	0	0	0	0	0	490	6.0
55	1	0	0	0	1	0	0	0	0	0	0	0	0	0	870	7.0
56	0	1	0	0	1	0	0	15	0	0	0	0	0	0	440	5.0
57	0	0	1	0	0	0	0	18	2.97	0	0	0	0	0.75	580	4.0
58	0	0	1	0	1	0	0	15	0	1	0	0	0	0	1090	8.0
59	0	0	1	0	0	0	1	22	0	0	0	0	0	0	490	3.0
60	0	0	1	0	0	0	0	12	0	0	0	0	0	0	564	4.0
61	0	0	1	0	0	0	0	0	0	0	0	0	0	0	640	4.0
62	0	0	1	0	0	0	0	18	0	0	0	0	0	0	580	5.0
63	0	0	1	0	0	0	0	0	0	0	0	0	0	0.50	502	2.0
64	0	0	1	0	0	1	1	37	0	0	0	0	0	0.75	1110	4.5
65	0	0	0	0	0	1	0	32	0	0	0	0	0	0.33	700	2.5

Table 13. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
66	0	0	1	0	0	2	1	0	0	0	0	0	0.75	0.50	1700	5.5
67	0	0	1	0	0	1	0	12	0	0	0	0	0	0.33	762	3.0
68	0	0	1	0	0	0	0	18	0	0	0	0	0	0	1000	4.0
69	0	0	1	0	0	0	0	15	0	0	0	0	0.50	0	344	5.0
70	0	0	1	0	0	0	0	0	0	0	0	0	0	0	980	5.0
71	0	0	1	0	0	0	0	12	0	0	0	0	0	0	400	3.0
72	0	0	1	0	0	0	0	25	0	0	1	0	0	0	1033	6.0
73	0	0	1	0	0	0	0	15	0	0	0	0	0	0.33	480	3.0
74	1	0	0	0	0	1	0	23	0	0	0	0	0	0.50	850	6.5
75	0	0	1	0	1	0	0	9	0	0	0	0	0	0	327	5.0
76	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1440	10.0
77	0	0	1	0	1	0	0	14	0	0	0	0	0	0	1180	6.0
78	0	0	1	0	1	0	1	11	0	0	0	0	0	0	950	8.0
79	0	0	1	0	1	1	1	17	2	0	0	6	0	0.50	2235	12.0
80	0	0	0	1	1	3	0	38	1.35	0	0	0	0	0	3667	14.0
81	0	0	1	0	1	0	0	0	1.62	0	0	0	0	0	1610	7.0
82	0	0	1	0	0	0	0	22	0	0	0	0	0	0	880	7.0
83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	490	3.0
84	0	0	0	0	1	0	0	0	0	0	0	1	0	0	668	7.0
85	0	0	0	0	1	0	1	20	0	0	0	0	0.50	0	560	8.0

Table 13. (Continued)

Farm No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Y
86	0	0	0	0	1	0	0	19	0	0	0	0	0	0	1600	7.0
87	0	0	0	0	1	0	0	12	0	0	0	0	0.75	0	700	8.0
88	0	0	0	0	1	2	0	12	0	0	0	1	0.75	0.50	1782	8.0
89	0	0	0	0	1	0	1	18	0	0	0	0	0	0.50	310	6.0
90	0	0	0	0	1	0	0	20	0	0	0	0	0	0	1040	8.0
91	0	0	0	0	1	0	0	22	0	0	0	0	0	0	360	5.5
92	0	0	0	0	1	0	0	12	0	0	0	2	0.75	0.50	470	5.5